THE FERTILITY OF THE LAND

A SUMMARY SKETCH OF THE RELATIONSHIP OF FARM-PRACTICE TO THE MAINTAINING AND INCREASING OF THE PRODUCTIVITY OF THE SOIL.

BY

ISAAC PHILLIPS ROBERTS

Director and Dean of the College of Agriculture and Professor of Agriculture in the Cornell University

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PREFACE BY THE EDITOR.

If a man has spent the greater part of his life as a teacher of agriculture and an experimenter, and has been a successful farmer at the same time, and has had the advantage of much travel, his opinions upon farm methods should be invaluable to his fellows. If, in addition to all this, he has had a philosophic turn of mind, and has persistently inquired into the reasons and results of all that he has seen, it would seem to be nothing less than a public misfortune if he should fail to leave some of his wisdom in permanent and consecutive form. At any rate, this has been my chief thought in persuading Professor Roberts to write this book. The book is, therefore, a personal one. It sets forth the author's philosophy of the means of maintaining the productivity of the land: and since the productive power of the land is the first and fundamental consideration in farming, it must follow that this book comes as near to being a treatise on agriculture as any single volume can be. It appeals to me with especial force, because it so well combines the current ideals of science with

the philosophy of farm-practice. It is the ripened judgment of the wisest farmer whom I have known.

I confess that I have looked with some apprehension upon the rapid diffusion of experimental science of recent years, for there is danger that this knowledge may overshadow the importance of accustomed farm-practice, and lead the farmer to demand specific rules for each perplexity and to depend upon the Experiment Station and the teacher for his farming. The most important mission of the Experiment Station, at the present time, is to lead the farmer to understand more fully the underlying reasons for the common things which he does. It is not too much to say that very few farmers really know the philosophy of plowing. The Experiment Station can, for the most part, work out only general principles and methods, and the farmer must modify and apply them as best he can; for each farm is a local problem, and each farmer must be an experimenter. When this conception of the Experiment Station work is fully apprehended, the farmer should become more self-dependent; and the necessity of working out a philosophy of his own, and of giving more careful attention to every detail of the tilling of the land and the husbanding of his home resources, will become more and more apparent. The farmer must approach the problem of maintaining the productive-

ness of his land from several directions, for the subject is a large one. He can use King's book on "The Soil" in considering it from the side of rational science, and the present volume will aid him in approaching it from the farm side.

There are those who look for the time when agriculture shall be reduced to a rigid science, which shall be governed by a well-defined series of rules and precepts. But that time will never come! Happily, there is one vocation in which men engage which can never be bounded by methods or precedents, one occupation which is as elastic and untrammeled and unconventional as the blowing of the wind, the falling of the rain, and the singing of the birds! The fact is that there is no science of agriculture. The occupation is a business and an art founded upon the inter-play of many sciences, of which chemistry, botany, physiology, physics and climatology are chief; and these and all the business methods are coördinated by good judgment and skilful management. There can be no text-book of agriculture, as there can be of botany or physics. Many of the so-called manuals of agriculture are really agricultural chemistries; they treat only one subject out of the score or more which may be considered to be fundamental. Chemical analysis — although of the greatest value in given instances—cannot tell what

the land will produce: it can only tell what it contains.

Farm-practice, therefore, is not the less important because we now have so much new light from science. It is a common saying that farmers are adhering too closely to the ways of their fathers, and the statement is undoubtedly true; and yet it must be remembered that we need not so much a revolution of farm-practice as we do an improvement of it. There is danger that in the bewilderment of the multitude of new facts, we forget fundamental reasons and the importance of understanding the common things. The farmer should be a philosopher. I like to think of him as having been so thorough and timely and resourceful with his work, that he can sit on the fence at least one day in the week and enjoy the fun of seeing things grow.

L. H. BAILEY.

CORNELL UNIVERSITY,
ITHACA, N. Y., March 1, 1897.

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A CHAT WITH THE YOUNG FARMER.

In the hurry and unrest of a new country, few have time or inclination to become familiar with plant and animal life as seen in the field and wood, and fewer still have looked upon the surface of the earth as anything but a mass of dirt, the particles of which are to be avoided or removed whenever they offend the sight or interfere with comfort.

Fill a flower-pot with the soft, dark earth and mold from the border of the wood, and carry it to the student of entomology, and see if he can name one-half of the living forms of this little kingdom of life; or hand it to the botanist, well trained in the lower orders of plants, and see how many of the living forms which these few handfuls of dirt contain he can classify. Present this miniature farm to the chemist and the physicist, and let them puzzle over it. Call in the farmer, and ask him what plants will thrive best in it; or keep the soil warm and moist for a time, and have the gardener say of the tiny plants that appear as by magic which are good and which are bad. Mark well what all these experts have said, and call in the orchardist to tell you how

to change dead, lifeless, despised earth into fruit; ask the physiologist to explain how sodden earth is transformed into nerve and brain. With this extended little field in view, choose the profession of agriculture if you love rural pursuits, but comprehend fully that in doing so you are entering upon the most difficult of all pursuits: difficult in ordinary times, doubly so under the present conditions, which have come about so rapidly that they are almost incomprehensible.

The American inherits from his European ancestors an inordinate desire for landed estates. In earlier days, many farmers acquired land by the square mile, and all secured more than they could farm well. The Federal Government sold at nominal prices, gave away and indirectly forced land upon all comers, not even reserving the hilly timber lands which, if they had been reserved, would have tempered the climate and have been an ever-present source of wealth. The Homestead Act has not brought unmixed blessings. The whole course of our federal policy towards public lands has tended to produce soil-robbers, not farmers. Transportation by steam power has made the products of vast inland areas salable, giving value to lands which were valueless, but the same power has also brought the products of Asia, Africa and South America into competition in the markets of the world.

From 1861 to 1865, vast numbers of men were transferred from the producing to the consuming class, and the prices of farm products became abnor-

mally high when measured by an inflated currency. These conditions could not fail to mislead and disappoint many when the population and the currency were restored to normal conditions. At the close of the Civil War, in addition to a vast influx of foreigners, there were added to the farming community many soldiers who, in the high prices, saw quick and large returns from the rich lands which had by this time been opened to settlers by the construction of extended systems of railway. During the third quarter of the century inventive genius so improved the appliances of agriculture as to quadruple the productive power of each farmer.

From 1870 to 1880, the percentage increase of new farms was 50.71 per cent, while the percentage of increase of population was 30.8 per cent. From 1880 to 1890, the increase was but 13.86 per cent, but the increase of population was 24.86 per cent. This shows that, for a time, the percentage increase of farms vastly outran the percentage increase of population. It also shows that the conditions prevailing before 1880 are being so rapidly reversed that the percentage increase in population may outrun that of farms far enough to greatly improve the home markets of many farm products in the near future. Be this as it may, the farmer is wise who adjusts himself quickly to present conditions, so unlike those of his father. To do this, he must see clearly and think straight; he must have good executive ability, as well as training and practice in well-defined business methods. To see clearly, the

eye must be trained to take in a multitude of objects quickly, to sort, compare and photograph on the sensitive brain those which are worth preserving. To think straight, many scientific facts, or items of knowledge, arranged in order, must be acquired, and these can be secured only by long, painstaking effort.

But to know is not enough; the ability to execute must be joined to knowledge, and executive skill is acquired in its highest form only by the direction and management of large affairs. It cannot be learned in the class-room, nor formulated in a text-book, and it is seldom learned by the farm boy because of want of opportunity; hence the lessons of the beginner are usually manifold, the tuition for the first term high, and the whole is paid for from his own resources, while young teachers, professional and business men get free tuition because they learn at the expense of their employers. What has been said of executive ability applies with nearly equal force to business ability, the lack of which in city and in country is evidenced in the newspapers by the word "assignment."

To the clear eye, to the intellectual equipment, to executive ability and trained business methods, must be added manual dexterity. Until recently the untold fertile acres, the favorable conditions, and the simple wants of the people, have arrested, in agriculture, the operation of that great law—the survival of the fittest. It has been said that "anybody can farm." That was, but is not true. From this time

on the struggle in farming will be such as it has been in mercantile affairs for some time. The unfitted in agriculture will have to yield for the same reason that many little factories, located off the lines of transportation, furnished with inadequate power, machinery and brains, have been abandoned. Many hillsides will be left to cover their nakedness with a new growth of hardy vegetation. It will thus be seen how well equipped the farmer should be, how fertile in brain, in imagination and in resources; how full of wisdom, of enthusiasm, of faith; how quick to see, how prompt to execute, how patient to endure under difficulties, if the fertility of his land is to be transformed into abundant and perfect fruits and flowers.

This book is dedicated to the young farmers of America. I am well acquainted with you all, though you are not acquainted with me, and being acquainted and older than you are, I cannot forbear entering into a little familiar chat. I know your thoughts, your toils and sorrows and discouragements; your aspirations, hopes and joys. I know, too, what fiber, endurance and patience farm work gives to the boys who make the most of what an outdoor life with nature has to offer. I know how hot it is in August under the peak of the flat-roofed barn, how large the forkfuls are that the stalwart pitcher thrusts into the only hole where light and air can enter. I know how high the thistles grow, and how far the rows of corn stretch out. I know, too, the freedom, fun and work of the old farm that make one expand,

enjoy and grow, and leave no bitter memories. I know you well, my boy,—how green and brown you feel when you come to the noisy city, and how you would like to be free and cool again!

You have seen for the thousandth time the long, wavy line of smoke as the train goes swinging by, winding in and out among the hills. Then you have longed to drive that mighty iron horse, feed him on fire, and make him leap away in wild freedom. Or, perhaps you do not aspire so high, and would be content to run a street-car. You have even admired the bright letters on the caps of the motormen, and you would exchange your freedom for the blue coats and shiny buttons. So intently have you longed to have some great corporation brand and number you, when the tasks at home were hard, that you have even planned to slip down those huge porch posts at night with your little bundle on a stick. But when night came you fell asleep, and the morning sun found you with thickened blood, temptation gone and courage for another day. Love and inherited pluck saved you. You were not ready for the city; you lacked knowledge, seasoned fiber and judgment. We never send colts to the city; they lose their heads and get "stove up" by rapid pace and rough, hard streets. The city may need you later, but sidewalks are hot and hard, while the country roads are soft and cool.

My scientific reader is getting anxious to know what manner of book this is, and in his heart he thinks I would better have been telling you how

energy is changed into heat, heat into motion, and then back into potential energy again. But let him wait; you and I are to finish our chat before we sit down to hard study.

All are greatly interested in you, my boy! We cannot see how to get along without you, and yet no one cares very much where you were born, where you live or how low you start, how high you climb or what you do, so long as you do right and lead a useful life. The world cares how you work, and it is interested in the progress of civilization. It asks that every one of you start from just where you are, without grumbling and with courage, and climb faithfully, honestly and in harmony with nature's modes of action, and the bars which guard the wealth of soil and the accumulation of man's toil will then fly back at your bidding. But wealth should be sought not for the pleasure of securing and possessing it, but as a means to higher ends. When rightly used, it relieves its possessor from a too severe struggle for mere existence, and gives time and opportunity for acquiring useful and pleasurable knowledge, which in turn naturally leads to a fuller comprehension of the real and enduring verities which, though unseen by the natural eye, are all that remain at the close of life. Financial reserves and mental training are the two great stepping-stones by which mankind may reach a higher plane of existence. On this higher plane, the environment is so broad and grand, the air so pure and thoughts so lofty, that all work, however menial, becomes inspir-

ing, and study, however hard, is pleasant and ennobling.

So, my young farmers,—who should be the pride of the nation and the anchor which holds the thoughtless from drifting towards anarchy,—be honest with the soil and with yourself. As you acquire health, fiber, purpose, and courage in mounting the first step, do not stop at the second or the third. Aim high, for it has been written: "Aim at the sun, and you may not reach it; but your arrow will fly far higher than if aimed at an object on a level with yourself."

In the hurry of this intensely utilitarian age, not only may health and life be curtailed, but the better and loftier sides of our nature are in danger of becoming dwarfed. While I may not stop to discuss the moral bearings of our profession, yet may I not ask my young reader to study what I have written in a broad and generous spirit, in order that the higher ends to be sought by study of the utilitarian side of the farmer's activities, which is presented in the following chapters, may be kept in mind!

CHAPTER I.

AN INVENTORY OF THE LAND.

The term fertility is commonly used in a special sense, meaning an abundance of nitrogen, phosphoric acid and potash, but its true meaning is productive power. One acre of land may contain thousands of pounds of plant-food and yet be infertile, while another one may not contain a liberal supply of the elements of plant growth, and yet be productive. If land contains a reasonable amount of potential plant-food and fails to give satisfactory results, it would appear to be both unbusinesslike and unscientific to add plant-food rather than to use that already in possession.

Large quantities of plant-food have been locked up in the fields since their creation, and might as well not have been created for all the good which they have yet rendered mankind. The first problem, therefore, that presents itself for solution, is how best to make available the stores of potential fertility in the soil. Before entering upon the subjects of cultivation and the physical characteristics of the land, an investigation should be made by questioning the soil, to discover approximately the amounts and availability of the plant-food in the land, what drafts it is desir-

able to make upon it, how it responds to the demands, and what is likely to be brought to the land from home resources.

Some soils respond quickly to tillage, and a portion of the potential plant-food which they contain is easily made available. Most light and sandy soils are of this character. Others, as heavy clays, in which the abundant elements of plant life are likely to be tenaciously held in combination with other matter, require skill and expensive treatment to make these elements available. Still another class contains deleterious compounds, which must be oxidized, or leached out, or some chemical action must take place to change the compounds into new forms which may be beneficial, or at least not injurious to plant growth.

A careful investigator discovers at once that productivity is not the simple question of lack or abundance of potential plant-food in the soil, and that, although productivity may be increased by adding or withholding one or more elements, the problem of how to most economically increase production is complex. It is not necessarily solved by the mere adding of fertilizing substances to the soil.

One writer has said that the best fertilizer for heavy clay land is blind drains; another, that deep plowing is the chief agent. Yet some portions of New Jersey were changed, between 1820 and 1850, from a sandy semi-desert into fruitful fields of wheat and maize, producing two or three times as much as the average yield of the state, by plowing which was seldom deeper than four inches. Others,

whose opinions are not to be despised, believe that the red clover plant is a universal panacea for the ills of impoverished soils; while Jethro Tull, that thoughtful benefactor of English agriculture, held strongly to the belief that frequent and appropriate horse-hoe tillage would result in maximum crops for an indefinite period of time.

The modern thought is to keep many domestic animals, and return in their voidings much of the plant-food removed from the land. But, manifestly, all persons cannot put this method into practice, and if they could, this scheme does not provide for waste and toll in many forms which must occur between the harvesting of the plants and the return to the fields of the residuum. Then, too, the physical conditions of the soil, the moisture stored in it, its temperature, the amount of sunshine, and other climatic influences, all play such important parts in the final results, that they not infrequently become a primary, and plant-food a secondary, factor in production. It is needless to multiply illustrations to show how complex and difficult the question becomes.

THE NATIVE PLANT-FOOD IN THE SOIL.

The following tables give forty-nine well authenticated analyses of American soils. In compiling them, care has been taken to use no analyses which seemed to be phenomenally low or high, as well as to secure those made by chemists of wide reputation:

TABLE I.

Analyses of surface soils.

No.	Nitrogen. N., %	Phos. acid. P_2O_5, %	Potash. K_2O, %	Moisture, %	Lbs. N. in 1st 8 in. soil.	Lbs. P_2O_5 in 1st 8 in. soil.	Lbs. K_2O in 1st 8 in. soil.	Analyst.	Source.	Year.
1	.379	.059	.062	3.686	8,310	1,294	1,360	N. T. Lupton	Ala. Bull. No. 1, new series	1888
2	.293	.056	.034	.981	6,250	1,194	725	"	" " " " "	"
3	.195	.196	.183	2.367	4,218	4,240	3,959	"	" " No. 2, " "	"
4	.282	.267	.866	7.468	6,436	6,094	19,766	"	" " " " "	"
5	.245	.05	.232	3.53	5,364	1,095	5,079	"	" " " " "	"
6	.26	.052	.348	3.676	5,700	1,140	7,630	"	" " " " "	"
7	.26	.029	.182	2.559	5,635	628	3,945	"	" " No. 3, " "	"
8	.26	.15	.903	3.676	5,700	3,289	19,800	"	" " " " "	"
9	.109	.032	.149	.817	2,321	681	3,173	"	" " " " "	"
10	.334	.038	.056	2.354	7,224	822	1,211	E. H. Jenkins	Conn. Report	1882
11	.14	.051	.047	.473	2,971	1,082	997	"	" "	"
12	.295	.037	.130	1.297	6,312	792	2,782	N. T. Lupton	Ala. Bull. No. 5, new series	1888
13	.04	.23	.23	{Sandy gray land} 3.150	872	5,016	5,016	D. O. Brine	Colo. " No. 9	1889
14	.09	.019	.019	Sandy .577	1,912	404	404	W. Bowman	Va. " No. 12	1892
15	.12	.23	.9	" loam .55	2,548	4,884	19,113	R. C. Kedzie	Mich. Bull. No. 99	1893
16	.07	.13	.83	Peach belt 2.23	1,512	2,808	17,929	"	" " "	"
17	.03	.22	.65	" .27	635	4,659	12,812	"	" " "	"
18	.09	.3	2.1	" 2.92	1,958	6,526	45,686	"	" " "	"
19	.07	.29	1.19	" 1.24	1,497	6,202	25,448	"	" " "	"
20	.12	.44	1.96	" 1.44	2,571	9,428	42,000	"	" " "	"

21	.10	.33	1.8	Peach belt	1.90	2,153	7,105	38,752	R. C. Kedzie	Mich. Bull. No. 99	1893
22	.11	.15	.83	..	.86	2,343	3,195	17,682	..	.. .. ..	..
23	.11	.28	1.95	..	5.38	2,455	6,250	43,526	..	.. .. ..	..
24	.04	.13	.89	..	.49	850	2,759	18,890	..	.. .. ..	..
25	.07	.21	1.1	..	.35	1,484	4,451	23,314	..	.. .. ..	..
26	.08	.18	.98	..	.65	1,701	3,846	20,833	..	.. .. ..	..
27	.08	19	.86	..	.52	1,699	4,034	18,260	..	.. .. ..	..
28	.03	.15	.54	..	.37	636	3,180	11,447	..	.. .. ..	..
29	.22	.49	1.85	..	2.1	4,746	10,571	39,910	..	.. .. ..	..
30	.16	.36	1.9	..	3.7	3,509	7,895	41,670	..	.. .. ..	..
31	.04	.14	.73	..	.4	848	2,967	15,480	..	.. .. ..	..
32	.06	.14	.92	..	.41	1,272	2,969	19,510	..	.. .. ..	..
33	.17	.38	1.18	..	.25	3,599	8,046	24,984	..	.. .. ..	..
34	.1	.2	1.13	..	1.43	2,143	4,285	24,212	..	.. .. ..	..
				Total		109,384	133,831	598,305			
				Average of 34 . .		3,217	3,936	17,597			

SUPPLEMENT (third edition).—The following are soil analyses made at the Cornell Experiment Station during the last two years. They show the amounts of plant-food in surface soils in New York state.

	Nitrogen, Per cent.*	Phos. Acid, Per cent.*	Potash, Per cent.*	Lbs. N in 1st 8 ins. of soil.†	Lbs. P_2O_5 in 1st 8 ins. of soil.†	Lbs. K_2O in 1st. 8 ins. of soil.†
I. Sandy loam (average of 8 analyses)..............	.125	.165	1.965	2,640	3,485	41,501
II. Clay loam (average of 11 analyses)................	.148	.156	1.415	3,126	3,295	29,885
III. Gravelly loam (average of 10 analyses)...........	.274	.248	1.605	5,787	5,238	33,898
IV. Loam (average of 8 analyses).....................	.274	.170	1.820	5,787	3,590	38,438
V. Slaty loam (1 analysis)........................	.150	.180	1.750	3,168	3,802	36,960
VI. Muck (average of 2 analyses)......................	2.295	.415	0.395	48,470	8,765	8,342

*These figures represent the *total plant-food* in the *water-free* soil. The nitrogen is determined by Gunning method; the phosphoric acid and potash by J. Lawrence Smith method of fusion.

†Calculated on basis of soil containing 12% moisture.

TABLE II.

Analyses of surface soils — Continued.

No.	Nitrogen. N., %	Phos. acid. P_2O_5, %.	Potash. K_2O, %	Moisture, %	Lbs. N. in 1st 8 in. soil.	Lbs. P_2O_5 in 1st 8 in. soil.	Lbs. K_2O in 1st 8 in. soil.	Analyst.	Source.	Year.
1	.14	.08	1.32	1.82	3,012	1,721	28,395	P. Schweitzer	Mo. Bull. No. 5	1889
2	.13	.07	2.54	2.44	2,814	1,515	54,986	"	" " "	"
3	.13	.06	1.17	2.31	2,810	1,297	25,295	"	" " "	"
4	.32‡	.045	.058	33.489	10,161	1,429	1,842	C. A. Goessman	Mass. Bull. No. 33	"
5	.048	.14	.25	8.85	1,112	3,244	5,793	F. F. Shutt	Canada Report.	"
6	.125	.06	.28	6.8	2,833	1,360	6,345	"	" "	"
7	.114	.13	.39	8.72	2,638	3,008	9,024	"	" "	"
8	.084	.822	.041	2.55	1,820	17,815	889	H. H. Nicholson	Neb. Bull. No. 13	1890
9	.056	.0623	.4107	1.373	1,199	1,334	8,795	"	" " "	"
10	.0735	.062	.741	1.806	1,581	1,334	15,938	"	" " "	"
11	.063	.0399	5927	1.8985	1,356	859	12,760	"	" " "	"
12	.071	.1127	.2413	1.876	1,528	2,426	5,194	"	" " "	"
13	.07	1.421	.197	3.382	1,530	31,062	4,306	"	" " "	"
14	.068	.0947	.0541	3.536	1,489	2,073	1,185	"	" " "	"
15	.204	.115	.96	1.25†	4,362	2,460	20,532	W. P. Wheeler	N. Y. Geneva. 8th An. Rep.	1889
Total					40,246	72,937	201,279			
Average					2,683	4,862	13,419			
" of 49 analyses (Tables I. and II.)					3,053	4,219	16,317			

† Average of 4 analyses. ‡ Peaty soil.

TABLE III.

Analyses of subsoils.

No.	Nitrogen. N., %	Phos. acid. P_2O_5, %	Potash. K_2O, %	Moisture, % *	Lbs. N. in 2nd 8 in. soil.	Lbs. P_2O_5 in 2nd 8 in soil.	Lbs. K_2O in 2nd 8 in soil.	Analyst.	Source.	Year.
1	.274	.093	.09	1.535	5,877	1,995	1,930	N. T. Lupton	Ala. Bull. No. 1, new series	1888
2	.253	.06	.092	.512	5,371	1,274	1,953	"	" " " " "	"
3	.087	.134	.171	1.494	1,865	2,873	3,666	"	" " No. 2, " "	"
4	.087	.152	.621	8.803	2,015	3,520	14,382	"	" " " " "	"
5	.087	.07	.233	1.753	1,870	1,075	5,009	"	" " " " "	"
6	.195	.085	.389	2.699	4,233	1,845	8,444	"	" " " " "	"
7	.239	.02	.194	2.469	5,175	433	4,201	"	" " No. 3, " "	"
8	.28	.174	.992	3.67	6,139	3,815	21,749	"	" " " " "	"
9	.087	.035	.174	1.267	1,861	749	3,722	"	" " " " "	"
10	.294	.027	.158	1.127	6,280	577	3,375	"	" " No. 2, " "	"
				Total . .	40,686	18,156	68,431			
				Average.	4,069	1,816	6,843			

* While the percentages of moisture in the original soils are given in these tables, they have all been computed at 12 % moisture, that the various soils might be more easily compared, one with the other; and the nitrogen, phosphoric acid and potash have been computed on the same basis.

The tables reveal the fact that even the poorer soils have an abundance of plant-food for several crops; while the richer soils in some cases have sufficient for two hundred to three hundred crops of wheat or maize. The average of thirty-four analyses (Table I.) gives to each acre of land, eight inches deep, 3,217 pounds of nitrogen, 3,936 pounds of phosphoric acid, and 17,597 pounds of potash, and this does not include that which is contained in the stones, gravel and sand of the soil which will not pass through meshes of ½ millimeter (1-50 of an inch), which, by weathering and tillage, slowly give up their valuable constituents.

Some plats at Cornell University grew, in 1895, 6,967.8 pounds of dry matter per acre of maize and stalks in hills, equal to 31,600 pounds of green material containing 77.95 per cent of water; and from other plats were harvested 26,000 pounds per acre of green oats and peas in 1896, containing 75 per cent of water. Samples of the soil from one of the plats, which grew the corn in 1895 and the oats and peas in 1896, were taken July 10, 1896, to determine the proportion which would pass through meshes of 1-18 of an inch, the amount of moisture, the weight of a cubic foot of soil, the composition of the soil which passed through the sieve, the proportion of pebbles which would not pass through, and also the composition of the rejected portion (the pebbles and stones), which was finely powdered by mechanical means and then separately analyzed. The results obtained are as follows:

TABLE IV.

Analysis of the samples.

Weight of soil per acre to the depth of one foot	2,082.5	tons.
" " the moisture	172.	"
Per cent original matter passed through the sieve	56.79	%
" " " " not passed through the sieve	41.85	"
" " loss	1.36	"
" " nitrogen in the fine material	.13	"
" " phosphoric acid in the fine material	.16	"
" " potash in the fine material	.51	"

TABLE V.

Amounts calculated per acre one foot deep.

In fine material.

Nitrogen	3,074.9	lbs.
Phosphoric acid	3,784.5	"
Potash	12,063.	"

In gravel.

Phosphoric acid	4,009.	lbs.
Potash	11,329.8	"
Per cent phosphoric acid in gravel	.23	%
" " potash in gravel	.65	"

Fine material and gravel.

Nitrogen	3,074.9	lbs.
Phosphoric acid	7,793.5	"
Potash	23,392.8	"

How much of this was soluble, and how much available, is not known.

The ten analyses of subsoils (Table III.) give an average of 4,069 pounds of nitrogen, 1,816 pounds of phosphoric acid, and 6,843 pounds of potash in the first eight inches of subsoil. So far as the averages are concerned we have accurate data, but in making computations per acre there must be an element of error, since the soil was not weighed. From approximate determinations, however, it is estimated that

ordinary soil weighs per acre, one foot deep, about 1,800 tons, or 1,200 tons eight inches deep.

In trying to discover how much plant-food there is in an acre, account must also be taken of its availability. It is well known that no soil can be entirely exhausted, yet it is equally well known that soils may produce well and still carry comparatively little plant-food. In the preceding tables, there is found in some instances as high as 8,000 pounds of nitrogen per acre in eight inches of surface soil, and 6,000 pounds in the subsoil, and 4,000 to 5,000 pounds are not uncommon. The phosphoric acid reaches, in one instance, 10,000 pounds in the surface soil and 3,000 pounds in the subsoil. The potash in the surface soil in a few cases (Nos. 18, 20 and 23, Table I.), is upwards of 40,000 pounds; in Table II. it rises to upwards of 50,000 pounds, or 2.08 per cent, while in the subsoil, Table III., it is 21,000 pounds. In the soils selected (Table I.), the average amount of potash in the first eight inches is 5½ times as much as the nitrogen, and 4½ times as much as the phosphoric acid. The average of the fifteen analyses, Table II., shows 5 times as much potash as nitrogen and 1.81 times as much phosphoric acid as nitrogen.

The subsoil is also rich in plant-food, but the material is not so available as that in the surface soil. By superior tillage, and by growing tap-rooted and leguminous plants, vast amounts of this dormant plant-food, uselessly carried in the subsoil from year to year, can be utilized; it is not best, however, to

reduce the amount to a low standard in the surface soil, since it is good economy to have a reserve for unusual conditions.

This vast store of plant-food is the farmer's stock in trade, the bank upon which he may draw. Its value can never be accurately determined, since a part of the plant-food is not available, and since the power of the plant to secure that which is available depends upon many conditions, such as the correct preparation of the land, the kind of crops raised, the relative amounts of the various required constituents, and the amount of moisture present. The table is interesting, since from it can be computed approximately what the same amounts of available plant-food would cost if purchased in the form of commerical fertilizers. It indicates and emphasizes how vast is nature's storehouse, and suggests that under good treatment much of her treasure may be utilized without endangering the productive power of the land. How much may best be utilized is largely a financial question, and can be solved only by the farmer himself. Those who are most expert in their methods, in recent years have come to the conclusion that increased production on good land is more cheaply secured by superior tillage than by the purchase of large quantities of fertilizer.

The average of forty-nine analyses (Tables I. and II.) show 3,053 pounds of nitrogen, 4,219 pounds of phosphoric acid and 16,317 pounds of potash, and $5\frac{1}{3}$ times as much potash as nitrogen, and nearly 4 times as much potash as phosphoric acid, in eight

inches of surface soil, per acre. Potash and phosphoric acid do not ordinarily leach out of the soil to any appreciable extent, for whenever they become soluble they pass down but a little way before they find and unite with bases which arrest their further progress, while nitrogen tends to leach out in the water of drainage. While it is not good economy to apply excessive amounts of any kinds of plant-food, it is doubly wasteful in the case of nitrogen. Frequent and light applications of nitrogen, one in the fall and one in the spring, are more economical than infrequent and liberal applications.

THE FOOD REQUIRED BY PLANTS.

If the amounts of the fertilizing elements set forth in the tables are compared with the composition of the plants to be grown, no certain knowledge as to which of the three elements should be added is revealed, since the one which appears to be the least might be the most available, and the one which is present in greatest quantity might be least available.

It is believed that the averages set forth in the above tables fairly represent moderately productive soils outside of the prairie land of the middle west and the semi-arid or arid lands of the extreme west. The Census Report for 1890 gives the average yield of wheat for the United States at slightly less than fourteen bushels per acre. Allowing that two pounds of straw are produced for every pound of

grain, and taking the average analysis of wheat and straw, the following amounts of plant-food are removed from each acre:

TABLE VI.

Plant-food in a wheat crop.

Nitrogen	29.73 lbs.
Phosphoric acid	9.49 "
Potash	13.69 "

Comparing these amounts with the average contained in the soil, and considering the yield of wheat per acre, which is only two-fifths of what is secured by large numbers of farmers, we are led to wonder what factors have entered into wheat culture to produce such a paucity of yield in the presence of such vast stores of potential plant-food!

It would require seventy-five tons of commercial fertilizer, containing approximately 2 per cent of nitrogen, 2.75 per cent of phosphoric acid, and 11 per cent of potash, to furnish as much plant-food per acre as the analyses show to be present in each acre, in a potential form, on an average, in forty-nine soils, after the land has been cropped half a century, and half as much more to equal that in the first eight inches of subsoil. The question arises, as it will often arise in the discussions which follow, how far tillage can be carried, and to what extent cover crops can be used, to make these vast, natural, ever-present resources of plant growth economically available. No one can even partially answer the question, except he asks the soil often and intelligently, and then modifies the answer to suit the methods and the

conditions which prevail at the time and place where the question is asked.

The average wheat crop removes but nine and one-half pounds of phosphoric acid per acre. Why is it not able to remove thirty-eight pounds and produce fifty-six bushels of wheat, when the first sixteen inches of the fine particles of surface soil contain, potentially, on the average, 7,122 pounds of nitrogen, 6,035 pounds of phosphoric acid and 23,160 pounds of potash per acre? Are the meager results due to lack of availability of these elements, or to lack of inherited power in the plant, or to imperfect physical soil conditions, or to insufficient moisture, or to all combined? Who can solve so difficult a problem!

Nearly all the inorganic constituents found in the ash of plants must be present in the soil, and in such forms that they may be set free by the action of the living roots. Some of the constituents, as salt (chloride of sodium), carbon, and others are not necessary to productive soils; plants grow without the former, and can procure the latter from the atmosphere. Their presence is not necessary, so far as growth is concerned, except as they may act beneficially on the texture, the moisture, or the organic or inorganic substances.

No certain information as to what amounts or proportions of the mineral constituents of plants are best is found by analyzing their ash. If a superabundance of one element is present, the plant may not only take up more than it requires for maximum

yield, but so much as to be positively injurious. Consider the case cited in Table II., No. 2, where 2.54 per cent of potash was present. If even a small per cent of this were available, the plant might use more than required for its highest development. On the other hand, plants, like animals, may thrive well on a somewhat limited supply of one or more required elements, if other conditions are favorable. Nitrogen, phosphoric acid and potash are seldom or never present in the same variety or species of plants in the same proportions, raised in different fields. They associate themselves in the living organisms not only by chemical affinities, but they are governed by many agencies, as hereditary forces in the plant, moisture, sunlight, heat and cold, presence or absence of an abundance of plant-food and the ease or difficulty of securing it. Analyses of soils and plants sometimes answer questions which could not be reached in any other way, and usually indicate the direction which should be taken to reach the most satisfactory results, but they are not of themselves of very great value, in most cases. As the most carefully designed piece of machinery may utterly fail when put to use, so the most analytical research into the mysteries of soil and plants may fail when applied, because other forces not taken into account may dominate or affect the results.

The previous tables show how variable soils may be, and yet be fairly productive. They also show how wasteful in many cases must be the application of a complete fertilizer, even though but a small

portion of the prime elements in the soil are available. Those who study the tables with a view of receiving aid in economical production of crops will discover at once that, having the facts revealed by the chemist for a basis, the real problems must be solved by putting questions to the soil and the crops in an intelligent way. To be more specific: having the composition of soil No. 19, Table I., an addition of nitrogen to it would naturally be recommended, since it contains less than half as much nitrogen, but a third more of phosphoric acid and potash, than the average of thirty-four soils; if the application were made, and no increase in crop followed, how can the unexpected result be accounted for? One or more adverse conditions out of a possible score may have been present, such as lack of moisture, unsuitable physical conditions, or lack of vital power in the plant to take advantage of the increased food supply; or the conditions as to moisture, soil, and the like, might have been of the best, and yet no increased yield result becaused the nitrogen already in the soil was largely available, and more would be superfluous and possibly even detrimental. The trouble might have been, in the supposed case, a lack of available potash or phosphoric acid The plant alone can tell if it can avail itself of enough of the mineral elements to make a good use of the additional nitrogen.

It has been shown, approximately, what amounts of nitrogen, phosphoric acid and potash are or may be in the soil; it has also been shown that it is

difficult, if not impossible, to know how much of it may be available for plant growth under given conditions. It is now in order to point out what demands are likely to be made upon the soil when some of the more common crops are grown.

The last census (1890) shows that 20,175,270 acres of cotton were grown in the United States in 1889, that it produced 7,472,511 bales of 477 pounds net, or 176.67 pounds per acre, and it is estimated that for each pound of lint two pounds of seed are grown, or 353.34 pounds per acre. The following table gives the composition in percentages, and the total amounts of nitrogen, phosphoric acid and potash in the seed and lint per acre of the average crop. Since the balance of the plant is not removed from the land, it may be ignored in this connection:

TABLE VII.

Analysis of cotton.

	Nitrogen, lbs.		Phos. acid, lbs.		Potash, lbs.	
Seed (353.34 lbs.).	3.07 %	10.85	1.019 %	3.6	1.16 %	4.10
Lint (176.67 lbs.)..	.28 %	.49	.066 %	.12	.637 %	1.13
		11.34		3.72		5.23

A good crop of cotton, such as is raised on well cultivated and fertile land, is one bale per acre, or $2\frac{1}{2}$ times the average yield, and therefore upon the better lands a draft is made of 28.35 pounds of nitrogen, 9.30 pounds of phosphoric acid and 13.07 pounds of potash by each annual crop. This is not a large demand, but if continued through a series of years without a rotation of tap-rooted or leguminous

plants, the readily available plant-food may soon fall to the point at which profitable cultivation ceases.

The unsatisfactory production and the unhealthy condition of many orchards which are mowed or pastured in central and western New York led naturally to the question: What demands have been or are likely to be made on the land by apple culture? Investigations conducted with the view of answering the questions must of necessity give only approximately correct data. The following tables,* which give the results in brief of two years' work will, it is believed, be of value, notwithstanding it is assumed that all of the trees in an acre of orchard are of the same size, fruitfulness and character as those weighed and analyzed. Assuming that thirty-five trees (one acre) would bear, thirteen years from setting, five bushels of apples yearly per tree for the next five years, and ten bushels for the next succeeding five years, and fifteen bushels yearly during the next ten years; and also assuming that the proportion of leaves to fruit was the same as found in the samples, and that the apples and leaves were all removed, the following results are reached:

TABLE VIII.

Materials used and removed from an acre by a bearing apple orchard in twenty years.

	Nitrogen, lbs.	Phos. acid, lbs.	Potash, lbs
Apples.............	498.6	38.25	728.55
Leaves.............	456.75	126.	441.
Trees (35)	283.15	107.45	264.25
	1,238.50	271.70	1,433.80

*Bulletin 103, Cornell Experiment Station.

Some of the leaves remain on the ground where they fall, but the greater portion is blown off the land which produced them. When the orchards are closely pastured or mowed, it is probable that the fertility carried off by pasturing or mowing equals that restored to the land by the leaves which remain; if so, the table would be approximately correct as to the total amounts of plant-food taken from the soil.

Foregoing tables show that an average soil (Table II.) has potential nitrogen sufficient for 32, phosphoric acid for 129, and potash for 240 crops of maize of 50 bushels per acre. The average crop of 1889 was 29.44 bushels per acre.

The table gives the amounts of nitrogen, phosphoric acid and potash in some of the leading crops computed on the average yield per acre, as given by the census of 1890:

TABLE IX.

Removed by one maize crop of fifty bushels.

	Nitrogen, lbs.	Phos. acid, lbs.	Potash, lbs.
Maize (3,000 lbs.) ..	54.6	21.	12
Stover (4,000 lbs.)..	41.6	11.6	56
	96.2	32.6	68

TABLE X.

Maize, 29.44 bushels per acre.

	Nitrogen, lbs.	Phos. acid, lbs	Potash, lbs.
Grain (1,766 lbs.)....	32.14	12.36	7.06
Stover (4,000 lbs.)...	41.6	11.6	56.
	73.74	23.96	63.06

Wheat, 13.95 bushels per acre.

	Nitrogen, lbs.	Phos. acid, lbs.	Potash, lbs.
Grain (837 lbs.).....	19.75	7.44	5.1
Straw (2,300 lbs.) ...	13.57	2.76	11.73
	33.32	10.20	16.83

Barley, 24.32 bushels per acre.

	Nitrogen, lbs.	Phos. acid, lbs.	Potash, lbs
Grain (1,167 lbs.) ...	17.62	9.21	5.6
Straw (2,300 lbs.)...	30.13	6.9	48.07
	47.75	16.11	53.67

Oats, 28.57 bushels per acre.

	Nitrogen, lbs.	Phos. acid, lbs.	Potash, lbs.
Grain (914 lbs.).....	18.82	7.49	5.66
Straw (2,400 lbs.)...	14.88	4.8	29.76
	33.70	12.29	35.42

Hay, 1.26 tons per acre.

	Nitrogen, lbs.	Phos. acid, lbs.	Potash, lbs.
Hay (2,520 lbs)	35.53	6.8	39

The total of the three elements removed from an acre by the maize, as shown by Table X., is 160.76 pounds, by the wheat 60.35 pounds, by the barley 117.53 pounds, and by the oats 81.41 pounds, estimating as nearly as possible the amount of stalks and straw which accompany an average yield of grain.

The figures show at a glance how small is the amount of plant-food used to sustain the average crop of the United States. Small, indeed, must be the amount used by crops which produce scarcely one-half the average. It should be noted, also, how small is the value and quantity of the fertilizing ele-

ments used compared with those contained in the average of the forty-nine soils given in Table II.

EXTRANEOUS SOURCES OF PLANT-FOOD.

Having shown what are the demands that are likely to be made upon the soil by a few of the most exacting crops, it will be instructive to go back and study Table I. more carefully, in order to determine what elements, if any, should be added. Acting upon the hints given in the table, it could probably be discovered approximately, by experimentation, how much of the plant-food could be made profitably available, and how much and what kinds should be added. It is always difficult to get clear ideas by discussing averages, because they may be made from combining extremes. A study of Table I. will show that a large number of soils exceed or come short of the average only in a slight degree, so that it may be concluded that these averages are not too high for the better agricultural districts.

While some of the soils show an abundance of potash and phosphoric acid, they are so lacking in nitrogen, presumably in that which is available, that not even an average crop could be raised. In some cases the soil carries vast quantities of dormant fertility in only one of the three forms, and this may not be available on account of its insolubility, and hence has not been used, or because one or two other elements are lacking. The latter condition is notably

the case in Nos. 18, 20, 23 and 30, Table I. These four soils each contain more than 40,000 pounds of potash per acre, or more than twice as much as the average, while the amount of nitrogen in 17, 24, 28 and 31 is less than the average; yet there is, indeed, enough to produce a crop if even a small per cent of it is available. These soils are carrying two or three times as much potash as is necessary; economy suggests that use be made of it. Since there is so large a surplus, probably half of it could be removed without any real injury to the productive power of the land. In addition to this vast store, the subsoil may be drawn upon, for in some cases there is more, and in many cases nearly as much, plant-food in it as in the surface soil. Since experimentation is the only method by which it can be determined how much can be made available by deep and tap-rooted plants, and by deep and thorough surface tillage, little profit can be derived from discussing this phase of the subject further, though it is probable that the larger proportion of this dormant energy can be made available. When it is realized how enormous is the amount of potential energy in both surface soil and subsoil, it should lead the farmer to better methods of tillage, and to put systematic questions to the land which he cultivates.

It has been shown what is or is likely to be in the soil, and what has been or may be taken out of it; it still remains to be shown what is added to the soil from outside sources, before tillage and implements can be discussed intelligently. In the humid

belt, except in mountain districts, from six to ten pounds of potential nitrogen are brought annually to each acre of land by the rainfall. To this must be added the vast stores of potential nitrogen secured through leguminous plants, which also bring to the surface considerable quantities of mineral matter which would not otherwise be available for the surface-rooted plants. (See Chapter XIV.)

Having these two sources, which may be called the incidental ones, to draw upon, there is still the third,—barn manures,—which is always present to a greater or less extent on every farm. American writers contend that barn manures are relatively rich in nitrogen and poor in phosphoric acid and potash, but European writers usually assert the reverse. This apparent contradiction most likely arises from different methods of comparison. If the comparison is made between that which the plant still requires, after having made use of the stored available nitrogen in the soil and that brought to it by the rainfall and the growth of leguminous plants, then barn manures may be considered relatively high in nitrogen. If the comparison is made between manures which have been exposed in open yards and the composition of the leading crops, then they may be said to be relatively poor in nitrogen. (See Chapter VI.)

If mixed husbandry is practiced, and a large percentage of the crops is fed to stock on the farm, nearly or quite half of the plant-food taken from the fields by the crop may be restored to it from this source alone. If, in addition to this, clover is

used in a short rotation, only a very small draft for mineral matter will be made on the original surface soil, and in many cases all the nitrogen required for ordinary crops may be supplied from the three sources named, though in some kinds of intensified agriculture large quantities, not only of mineral matter but nitrogen as well, may be profitably added in concentrated fertilizers.

If Table X. is considered in reference to mixed husbandry, with clover in the rotation, it will be seen how small an amount of plant-food must be taken from that already in the soil to produce an average crop; and when considered in connection with Tables I. to III., the demand of the plant upon the stores in the soil is comparatively so small that it is a wonder that larger crops than those given in Table IX. are not the rule rather than the exception.

Since the soil and the subsoil contain such stores of potential fertility, and since tap-rooted leguminous plants bring to the surface abundant quantities of nitrogen with some mineral matter, and since many fields receive applications of farm manure from time to time, some far-reaching cause or causes must be present ever tending to seriously restrict production. It will be found that in this country the principal causes of low yields of farm crops are imperfect preparation of the land, poor tillage and hence a lack of available plant-food, and insufficient moisture during some portion of the plant's life.

A hasty survey of the land having been made, it

is found that the low average yields are not usually due to lack of potential plant-food in the soil, and that most agricultural plants never have full opportunity to come to their best estate, as the meager average yield and the inferior quality of many of the products of the farm abundantly prove. The lack of appreciation and utilization of nature's storehouse and laws suggests a discussion of the plow, which now follows.

CHAPTER II.

THE EVOLUTION OF THE PLOW.

THE following history and illustrations are given that the reader may carefully study the growth and improvement of implements for tilling the earth, thereby arriving at the true principles and most economical methods which should obtain when that most laborious and expensive operation of agriculture, —preparation of the land for crops,—is undertaken. The history is of necessity far from complete, and full credit cannot be given to all who may deserve it, nor can we arrive, in so brief a sketch, at full historical agreement as to priority of improvement.

DEVELOPMENT OF THE PLOW IN THE OLD WORLD.

Sculptures on ancient monuments, dating back 4,000 years or more, give conclusive evidence that

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NOTE.—The following definitions of terms used in describing plows may be useful to those who have little acquaintance with the subject:

Bridle. The clevis at the end of the plow beam, for controlling the depth and width of the furrow

Colter or Cutter. A steel-edged circular or knife-like blade attached to the beam, for severing the perpendicular side of the furrow from the adjoining land.

Lock Colter. One which is united by the back of its point with the point of the share.

Land-slide. That part of the plow on the opposite side from the moldboard.

Share or Point. A broad steel or iron plate attached to the lower side of the moldboard, for severing the furrow slice horizontally.

Jointer or Skim Plow. A small steel or iron attachment by which a miniature furrow is cut and turned in advance of the plow. (See Figs. 14, 15.)

the plow was then in common use, and it probably had been used for preparing the land for plants cen-

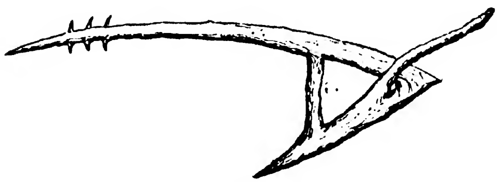

Fig. 1. One of the earliest types of plow.

turies before. It is believed by Bible critics that the Book of Job is one of the most ancient writings of the Old Testament, yet the first chapter alludes to the plow: "The oxen were plowing and the asses feeding beside them."

A few illustrations will serve to show the essential characters of the types of primitive plows:

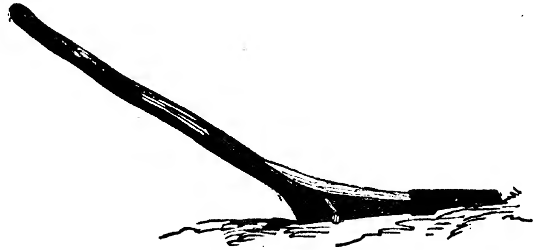

Fig. 2. East Indian plow.

Fig. 1 is from an ancient monument in Asia Minor, and represents one of the most primitive

forms of implements of tillage, being simply the crooked branch of a tree, with the exception of the

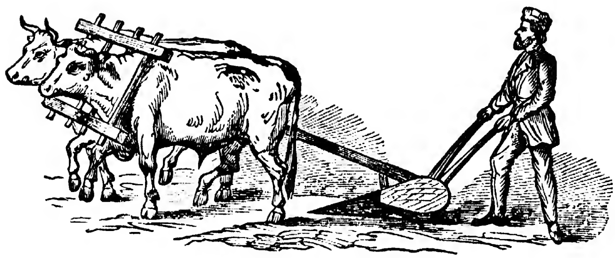

Fig. 3. Egyptian plow.

brace *e*, and the pins near the end of the beam, which were used for attaching the plow to the yoke. Fig. 2, from a model of an East Indian plow in the Agricultural Museum of Cornell University, is said to be the only plow still used in some parts of India. In ancient times it was used in British husbandry,

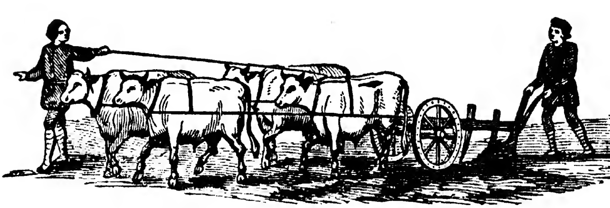

Fig. 4. Eleventh century plow.

and appears to have been the first effort to cover the point with iron. Fig. 3 shows a plow used in many

parts of Egypt and Mexico, and one not entirely discarded at the present day. Fig. 4 illustrates the English plow of the eleventh century, used in the time

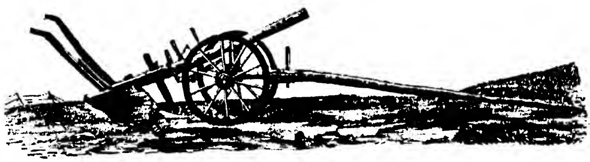

Fig. 5. French plow.

of William the Conqueror. Fig. 5 represents the form of plow that is still in use in many parts of France. Although the improved plow has been introduced into the better agricultural districts of France, plows with some form of trucks placed under the beam, which is set at an acute angle, are not uncommon. The attachment of the beam near the colter

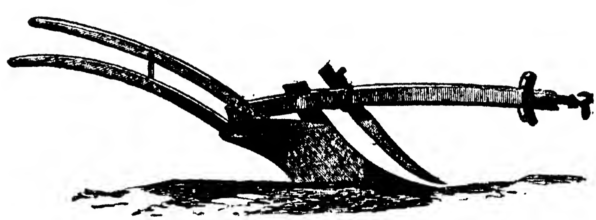

Fig. 6. Early Dutch plow.

by a chain gives great flexibility. Slightly modified, this method of attachment would appear to be more scientific than the one in common use in America, as

the plowman has the long end of the lever; that is, it is a greater distance from the standard to the ends of the handles than from the standard to the point at which the team is attached.

The fundamental idea of our present plow seems to have been derived largely from Holland. Fig. 6 is a cut of the plow used in Holland at the beginning of the eighteenth century. It was introduced into Yorkshire, England, and became popular among pro-

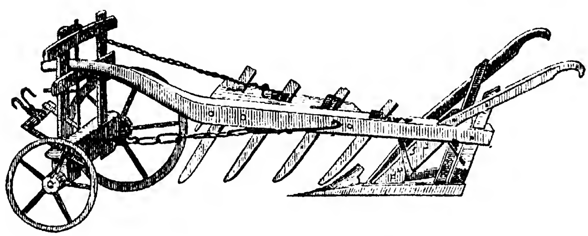

Fig. 7. English plow of last century.

gressive farmers. From this time on the improvement of the plow was rapid. Fig. 7 is an illustration of the Berkshire plow used in England in 1730, and highly recommended by Jethro Tull. At that date Tull had already made a careful study of the science of tillage. He saw that agriculture needed implements to divide the soil more perfectly, not only before the seeds were sown, but afterwards. He seems to have comprehended very fully the needs of English agriculture, and although he made many mistakes, he still did a wonderful work by inventing the drill, practicing horse-hoe tillage, and by empha-

sizing the need of better tillage in order that a more economical use might be made of the stored elements in the soil. A principle laid down by him was that "tillage, and tillage alone, will create and supply the food of plants, and will, in most cases, render manure wholly unnecessary. By dung we are limited to the quantity of it we can secure, which, in most cases, is too scanty. But by tillage we can enlarge our fields of subterranean pasture without limitation, though the external source of it be confined within narrow bounds. Tillage may extend the earth's internal superficies in proportion to the division of its parts, and as division is infinite, so may the superficies be. Every time the earth is broken by any sort of tillage or division, there must arise some new superficies of the broken parts which never have been opened before; for when the parts of earth are once united and incorporated together, it is morally impossible that they or any of them should be broken again only in the same places; for to do that, such parts must have again the same numerical figures and dimensions they had before such breaking, which, even by an infinite division, could never be likely to happen."*

It will be seen how close and accurate Tull's reasoning is with the exception of two clauses: one asserts that "by tillage the subterranean pasture can be enlarged without limitation," and the other that "tillage, and tillage alone, will create and supply

*Jethro Tull, The Horse-hoeing Husbandry. (Published by William Cobbett, London, 1829. Introd. by Wm. Cobbett.)

the food of plants." This should, of course, be modified, for pasturage cannot be enlarged indefinitely, nor can tillage create plant-food.

By his drill and horse-hoe methods, Tull succeeded in raising twelve wheat crops continuously on the same land without manuring, and without any marked diminution in the yield per acre. Had he studied the mechanical forces which are concerned in the minute division of the soil by the plow as closely as he did the wants of the plants and the means of

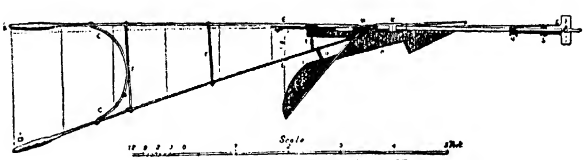

Fig. 8. East Lothian Scotch plow.

supplying them, he might have seen that the Berkshire plow was not well adapted to pulverizing the soil in the most economical manner. In order to fine soils economically, their particles should be made to grind each other by attrition, according to the principle used in polishing rough castings. It has recently been found, by careful experiments, that dividing the soil by colters, or even by a single colter, requires a large amount of force, and that to break and crush the soil by concussion or attrition is the most economical way of pulverizing it. It is, therefore, no wonder that the Berkshire plow was soon super-

seded by others, which had overhanging moldboards and a single colter placed close to the standard and shin of the plow. Tull had no means of determining the loss by friction due to the weight of the plow alone, amounting in some cases to 30 per cent of the

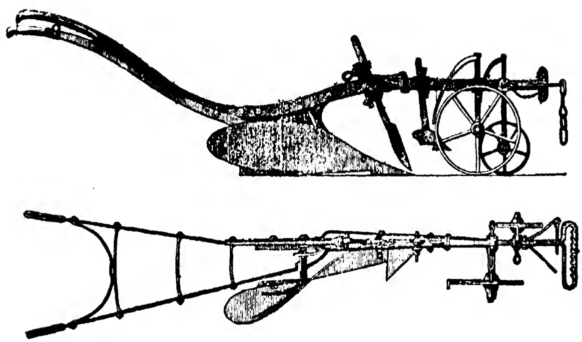

Fig 9. Midlothian or Ransome plow.

entire draft; nor did he, apparently, suspect how greatly the draft of the plow was increased by the added colters.

The plow of East Lothian, Scotland, is shown in Fig. 8. Some of its distinctive features have been retained in parts of Europe to the present day. Its extreme length, and lack of width and twist, indicate that narrow, straight furrows must have been then, as in fact they still are, the pride of the Scotch plowman. Tull, in his zeal to fine the soil, overlooked the unscientific and expensive means by which it was accomplished. The British plowman,

in his zeal for straight furrows and easy draft, overlooked pulverization of the furrow, which is or should be the chief object of plowing. Fig. 9 illustrates the Midlothian plow, modified and improved. Plows similar to this are still in common use in many parts of Great Britain. The long wedge shape is still preserved. The skim or jointer plow, so successfully used in the United States in a few localities, is an adaptation of this type. Such plows are adapted only to land free from stumps and stones, and they illustrate the English idea of laying flat furrows, in which respect the English method differs radically from the American, which seeks to break up the furrow by bold, overhanging moldboards, to the detriment of the appearance of the plowed land.

All of the foregoing illustrations show that until very recently the effort of the plow-maker has been directed largely towards producing an implement of light draft by constructing it on sharp wedged lines, with little reference to pulverizing efficiency. For the most part he ignored the draft due to the weight of the plow, and also the economy of the bold, overhanging moldboard, whereby the furrow is broken and robbed of its tenacity and left in a corrugated condition, so that the other implements of tillage may do their work effectively. Observation leads to the conclusion that in England twice as much surface tillage is given in preparing the seed-bed as in America, due, without doubt, chiefly to the imperfect principle on which their plows are

constructed. It is no uncommon thing to see the furrows on sod ground laid as flat as shown in Fig. 16 (Chapter III., page 65), or as little disturbed by the action of the moldboard as in Fig. 17 (page 66). It is quite evident that the plow has developed in England and America on very different lines.

In 1785 Robert Ransome, of Ipswich, England, succeeded in making plowshares of cast iron. This was a great step in advance of the old method, by which each share was formed according to the skill of the blacksmith. Until this time, most of the improvements of the plow were lost at the death of the genius who had invented them. Arthur Young writes in his Agricultural Report of Suffolk, that "a very ingenious blacksmith of the name of Brand made a plow of iron," and adds that "there is no other in the kingdom equal to it;" but this valuable improvement passed away with the inventor. In 1803, Ransome discovered and patented a method for case-hardening or chilling shares. The ordinary cast share, unhardened, became quickly blunted and, since it could not be sharpened, had to be exchanged for a new one. The case-hardening of about one-sixteenth of an inch on the lower surface preserved to a considerable extent the sharp edge, since the upper and softer portion of the share wore away faster than the lower. The bridle or clevis at the end of the beam, to control the width and depth of the furrow, had already been invented.

DEVELOPMENT OF THE PLOW IN AMERICA.

Among the stumps and stones of New England, and even in the Middle states, the long English plow could not be used to advantage. While we brought from England and Holland, to a great extent, our methods of living, tools, styles of architecture, and our government, the foreign idea of plows and

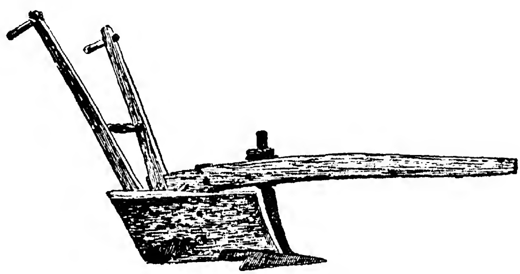

Fig. 10. Ancient Yankee plow.

plowing had to be radically modified. Fig. 10 represents a plow in the Agricultural Museum of Cornell University, which was used in Connecticut over one hundred years ago. The moldboard is formed from a section of a winding tree, the grain of the timber running as nearly as possible parallel with the movement of the furrow. It was protected by nailing upon it refuse band-iron, wornout horse shoes, and old hoes. A share and lock-colter were provided, the latter being necessary to prevent the roots from passing backward to the standard of the plow before they were cut or broken by the colter. Here we have, as compared with the European plow, the

other extreme, the beam and moldboard short and the handles erect, enabling the plowman to more easily plow around obstructions, and to till the land to the very roots of the stumps. The point of the share was bent sharply downward to prevent it from rising to the surface; and, therefore, wherever the soil was fairly free from roots and stones it would run too deep. To overcome this difficulty, a wooden shoe was placed near the end of the beam, to govern the depth of the furrow better than a wheel would on rough land. The length of the beam of the modern American plow is not much greater than that shown in Fig. 10, although nearly all plows are now used in lands free from stumps and large stones.

In 1780, Thomas Jefferson, American ambassador to France, made a study of the plows used at Nancy. He makes the following note: "Oxen plow here with collars and hames. The awkward figure of the moldboard leads one to consider what should be its form." In 1793, Jefferson put his theory of cone-shaped moldboards to a test at Albemarle, Bedford county, Virginia. The lines of his plow were formed on what appear to be true mathematical principles, but it failed to accomplish all that was desired, for it neither turned the furrow well nor pulverized the soil satisfactorily.

The first American after Thomas Jefferson who interested himself in a large way in the improvement of the plow was a farmer, Charles Newbold, of Burlington, N. J. He made the first American

cast-iron plow, and took out letters patent for the same on June 26, 1797. Prejudice against this "new-fangled" plow was so great that it did not come into general use, the farmers believing that cast-iron plows poisoned the land and caused weeds to grow. The latter accusation was certainly true, for weeds respond to improved cultivation quite as readily as the better cultivated plants do. Newbold later substituted a wrought-iron share for the cast one, but it did not overcome the early prejudice which had been formed against his plow.*

In the first volume of the Transactions of the Society for the Promotion of Agriculture, Arts, and Manufactures. New York, it appears that in 1794 Colonel John Smith produced a model of a cast-iron plowshare that "should save expense in husbandry," which he proposed to substitute for the common forged wrought share then in use. Later he modified his cast share by riveting to it a false wrought-iron or steel edge. The object of this was to make it capable of being sharpened from time to time, and thereby obviate the renewal of the entire share when dull.

In 1807 David Peacock, of New Jersey, took out patents on an improved plow which came to be very valuable, and as the prejudice against the cast plow had measurably passed away, it came into common use. It is probable that it was very similar to Mr. Newbold's plow, since he received from Pea-

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*For details and specifications of various plows, see "Utica Plow Tria'," 1867. Trans. N. Y. Agric. Soc. xxvii., Part I.

cock $1,500 as a satisfaction for an infringement claim.

In 1820 Timothy Pickering, who took a very active interest in the improvement of the plow, says in a letter to Dr. Coventry: "My opinion is that the straight lines are essential to the form of the moldboard of the least resistance." Here, again, ease of draft instead of efficiency of the work done by the plow is made foremost.

The fact that a plow having a correct form might be made to accomplish a large part of the work of fining the soil had not yet attracted attention either in Europe or America. Effort was largely directed to forming a moldboard that would turn the furrow, and when one had been constructed that fined the soil better than others, it was discarded if the draft chanced to be a little more than that of the plows in use. The reasoning was somewhat as follows: "In adjusting the moldboard of the plow, another point is to be determined,—the extent of the angle which the essential straight line should form with the bar of the share or land-side of the plow, for the smaller this angle the less the resistance at entering the earth; but if the angle were to be very small, the plow must have great length to obtain a proper breadth of furrow; *and such great length would proportionately increase the quantity of friction.*" * It is readily seen that an error of reasoning has crept into the last clause of the quotation, for friction is not increased by lengthening the

* Report of the "Utica Plow Trial," 1867.

moldboard, other things being equal. Supposing the resistance of the moldboard to be represented by 100, the total friction will not be increased by distributing it over a larger surface, or diminished by confining it to a smaller one. It is true that a bold moldboard will cause more friction than a straighter one, but this would be entirely due to the greater resistance produced by the bolder wedge, and not to the fact that a less surface presented itself to cutting and twisting the furrow-slice; or, to illustrate, a board draws as easily on its flat side as on its edge. Other things being equal, the amount of friction is determined by the character of the surface and the weight independent of extent of surface, which would not be true in case of fluid friction.

As soon as the cast plow was an assured fact, the next effort was to make it of three or four interchangeable parts, that it might be easily repaired. Numerous patents were taken out for minor changes in the draft-rod, clevis and wheel. The lock-colters became common in the wooded districts, and were a great improvement over those which allowed the roots to pass back of the colter to the standard without being cut, in which latter case the plow had to be relieved by severing the roots with an ax.

In recent years, plow-makers have modified the character of plows somewhat by increasing the length of the share, beam and handles, and by placing the handles lower and at a less acute angle than formerly. Why these changes did not come about

sooner,—as soon as the fields were cleared of obstructions,—it it difficult to understand, for they give better control of the plow than the shorter construction, without impairing the efficiency of the moldboard.

In 1839, Samuel Witherow and David Pierce saw the need of a plow which would accomplish in a larger degree the fining of the soil. They say:

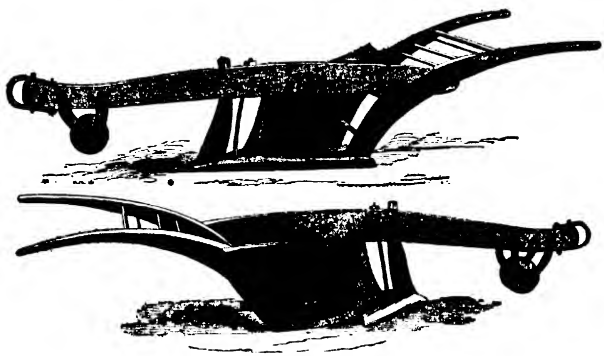

Fig. 11. Daniel Webster's plow.

"Having thus fully set forth the nature of our invention, and shown the manner in which we carry the same into operation, what we claim therein is, the giving to our moldboard the segment of a cycloid convexly on its face in a line leading from front to rear, and concavely in the lines of the ascent of the furrow-slice, the object being to cause various parts of the furrow to move with unequal velocity. The main object is *to pulverize the soil*, and the only way in which it can be effected is by bending a furrow-slice on a curved surface so

formed that it shall also be twisted somewhat in the manner of a screw."

In 1836 or 1837, Daniel Webster invented a plow capable of handling a furrow twelve to fourteen inches deep. It was twelve feet long from bridle to the tips of handles, the land-side four feet long, and the bar and share were forged together. The wooden moldboard was plated with strips of iron, and had a breadth at the heel to land-side of eighteen inches, with an extreme spread at the rear of twenty-seven inches. The plow was provided with a lock-colter and a wrought-iron steel-edge share. Four yokes of oxen were required to draw this huge plow, which was capable of turning a furrow twelve inches deep and two feet wide in the old pasture fields which had become partly overrun with bushes and even small birch trees. In later years, iron plows similar to this were used in the west to subdue the hazel border which frequently joined the timber belt to the prairies. These plows were the fore-runners of the great "prairie breaker."

In 1843, T. D. Burrell, of Geneva, N. Y., endeavored to reduce the friction of the land-side by substituting for it a wheel. This attempt has been made many times since, but has not been successful, since the wheel becomes obstructed and immovable, and is then not so good as the ordinary land-side.

About 1860, trench plows were made, but they were little used for deep tillage; they were fairly well adapted for digging ditches, but they have gone out of use. Most farmers do but a small amount

of underdraining each year, and it is found to be more economical to use the common plow for partly opening the trenches than to keep an extra one for that sole purpose.

A little prior to this time, there was a general discussion as to the depth to which plowing might be profitably carried, which led to placing two plows upon one beam. The first plow took off three or four inches of the surface soil and deposited it at the bottom of the furrow. The second and larger plow was set to run six or seven inches deep, and deposited its furrow on the top of the first one. This trench plowing was not only expensive, as it required great power, but it deposited the subsoil on the surface and the vegetable matter at the bottom of the furrow, a state of affairs which often resulted in poor crops for several years, or until the inert matter in the upturned subsoil could be set free by surface tillage. These plows have never come into common use.

A later outcome of this same discussion was the subsoil plow, which loosened the earth in the bottom of the furrow, but did not bring it to the surface. On certain lands subsoiling is beneficial, but it was soon found to be better economy to loosen the subsoil by underdrains and clover than to go to the expense of loosening it every few years by the use of the subsoil plow. These, also, to a great extent, have gone out of use. At the present time an effort is being made to revive them, it being contended that subsoiling is very beneficial, in

that it enlarges the power of the earth to store up water, thereby mitigating or preventing the effect of droughts. This contention is true in part, but when to use the subsoil plow and when not to use it are matters of local economy and expediency.

PRAIRIE PLOWS.

The first western emigrants, who settled in or near the belts of timber at the verge of the great prairies, soon found that the open prairies were easier to reclaim and far richer than the fringe of wood which bordered upon them. Little difficulty was experienced in subduing the tough prairie sod with the great breaking-plows, even though it required a strong team, for oxen and steers were abundant and cheap. Ten or twelve yokes were sometimes attached to one plow, the team being driven by one man on foot or horseback. A well-broken yoke of cattle was placed in the lead, a heavy yoke at the beam, and the balance of the team was made up of unbroken steers, which became more valuable from week to week because of the training which they received. Most of these plows had truck-wheels attached, so that they required no holding. They cut a furrow from eighteen inches to two feet wide and about two inches deep. The moldboards were sometimes formed of rods of iron, and were set at such angles as would kink the furrow and leave it on edge, so that during dry weather the grass would perish for want of moisture. The following

spring the ground was harrowed or replowed before sowing.

As emigration extended further west into the dry belt, where the prairie sod was less tenacious on account of limited moisture and the trampling and feeding of numerous cattle, the method of breaking up the land became somewhat modified. Three

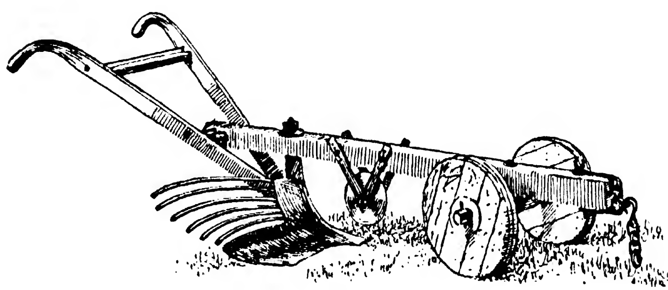

Fig. 12. An old-time "prairie-breaker."

horses attached to a steel plow with rolling colter could perform the work. The share and colter were both filed every few hours, that they might the more easily cut the tough grass roots. Fig. 12 represents one of the old-style prairie-breakers, with the beam nine to ten feet long, and capable of withstanding almost any amount of strain. Owing to the changed conditions noted above, this plow has become nearly obsolete. As soon as the native grasses were destroyed the American plowman, as well as the plow-maker, discovered that economy required much of the pulverization of the soil to be

done by the plow alone, in order to save labor in fitting the seed-bed. This fact was not fully realized in the United States until agriculture reached the great prairies, where the mellowness of the soil and the immense areas to be cultivated soon developed a plow which could fit stubble land for a succeeding crop with little or no subsequent treatment. As soon as the grass roots were rotted and the land was well subdued, there was great difficulty in securing a plow that would "scour," or clear itself. As high as $100 was offered by one of the early settlers in LaPorte county, Indiana, for one that would "scour" and do good work.

Between 1860 and 1870, a glass plow was invented. It failed to meet expectations, since it did not scour as well as those already in use. To stand the strain it was made heavy, was likely to break, and, therefore, it never advanced beyond the experimental stage. If the action of the ancient wooden moldboard had been carefully observed, it would have been discovered that it possessed the quality of scouring beyond all other moldboards except those made of hardened steel.

DEVELOPMENT OF CONTEMPORANEOUS PLOWS.

The next effort was to construct a plow with a steel moldboard, which was hardened by chilling the outer surface after heating in layers of charcoal. Before purchasing, the farmer tested the moldboard with the sharp point of a knife; — if a scratch could

be made the plow was condemned. These plows often worked well for a time, but the unequal wear and the unequal hardening resulted in developing soft spots in the moldboard, to which the dirt would adhere and around which it would build until the plow was little better in efficiency than those shown in the first illustrations in this chapter. The writer has plowed in early spring when the plow persisted in becoming more rusty every day, although the moldboard was cleaned with a wooden paddle at frequent intervals. As the season advanced, and the ground became drier and firmer, the same plow would work satisfactorily.

For several years the moldboards of plows were hardened in hot oil, in order to overcome the difficulties that were met with when only the outer surface was hardened. This was a fairly successful but very expensive method, because in the operation many of them would twist or crack. To overcome this difficulty, a layer of steel and a layer of soft iron were welded together to form the moldboard, and this preserved its shape during the hardening process.

By a process lately invented, moldboards are made of three layers of steel welded together, the middle one being soft and the two outer ones hard. Afterwards they are shaped and heated, immersed in a preparation, varying with different plow-makers, and held firmly by clamps while cooling. By this means the shape is preserved and the tension very largely overcome by the middle layer of soft steel.

The practice of carbonizing or chilling the face of the moldboard of both steel and cast-iron plows has become common. To accomplish this, several methods are in use, all of which aim to harden the face of the metal, and to cause it to form crystals at right angles to the surface on the outer or wearing side, while preserving a soft, laminated structure on the opposite side. One method is to form the lower half of the matrix, which is to receive the melted material, of iron, and the upper half of sand. The metal part of the mold into which the iron is run causes the crystals to arrange themselves at right angles to the face of the moldboard, and also hardens the forming moldboard for the greater part of its thickness, while the back of the casting, which rests against the sand of the mold, remains soft. This process, or a similar one, is now in universal use, and plows constructed in this manner scour better and are more durable than formerly was the case.

From 1861 to 1865, and for some time subsequent thereto, wages on the farm were high, and the plowmaker, seeing his opportunity, constructed gang plows: that is, two or three plows fastened to one or more beams. This resulted in economy of plowmen, but as it could be operated only by able-bodied men, it was quickly followed by the sulky plow. This not only had all the valuable qualities of the unmounted gang-plow, but it also allowed the use, as drivers, of women, children and cripples,—a great consideration in war times. By the use of wheels

a large portion of the weight of the plow was transferred from the ground to the axles of the sulky, and this was such a great saving in power that it was possible to make a plow, including the sulky, of three or four times the weight of the ordinary one, mount upon it a plowman, and still not increase the force necessary to do the work. Wherever the fields are reasonably large and the ground adapted to their use, the work can be done better with these implements than by the ordinary walking plow.

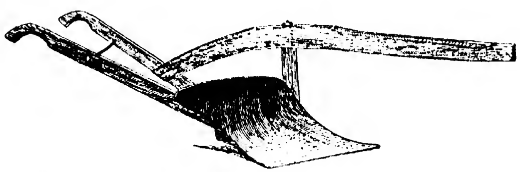

Fig. 13. Prairie stubble plow.

Often a gang of two or three plows is attached to one sulky, and drawn by several horses managed by a single plowman, thereby reducing the cost of laborers materially. This method of plowing has been practiced more extensively in California than in any other state, and it is not uncommon to see eight lusty horses attached to a sulky gang-plow, in the great wheat districts of the Sacramento and other valleys.

The highest development in the plow is seen in the three accompanying pictures. Fig. 13 represents a steel prairie stubble plow without clevis or rolling cutter. Its lightness, overhanging moldboard, and

broad, flat share, which enables the plow to cut a sixteen-inch furrow, are features which enable it to

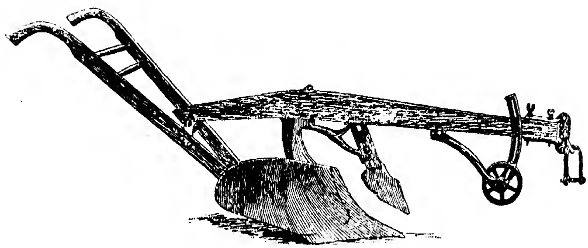

Fig. 14. A model wood-beam plow.

perform its desired work with ease, cheapness and efficiency on the stoneless prairies. Figs. 14 and 15 show plows built on much the same lines as are shown in Fig. 13. The shares are not so flat and broad, and the moldboards are larger and not so

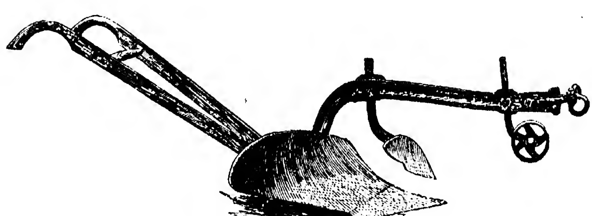

Fig. 15. The ideal plow.

overhanging. The plows are heavier, and in all things have been most admirably adapted to hard

and stony land, and to plowing both stubble and sod when the jointer attachment is used.

The American plow has taken the form best adapted to fitting the land cheaply and well, without much reference to straight and beautiful furrows, and hence the evolution of the plow in the United States has been along new and original lines. Discovery has followed discovery rapidly, the plow-maker can now procure the best of material, and it may be said that no other country produces so many varieties of plows which are so good or so well adapted to varied soils and conditions as America does. As a result of the great improvements in plows of American manufacture, these implements are now exported in large numbers to South America and various parts of Europe, and also to Japan.

Through all these centuries how slow has been the evolution of the plow! So far no implement has been invented to take its place, nor has any success come to inventors who have departed from the principle of combining two unequally twisted wedges, one acting in a horizontal, the other in a perpendicular plane. Whenever the farmer will consent to furnish more power, the evolution of the plow will continue along the lines of greater depth and more perfect pulverization of the soil, whereby augmented available fertility and increased conservation of moisture will be secured.

This narrative recalls the noble words of Jethro Tull, written early in the last century: "Men of the greatest Learning have spent their Time in contriv-

ing Instruments to measure the immense Distance of the Stars, and in finding out the Dimensions, and even Weight of the Planets: They think it more eligible to study the Art of plowing the Sea with Ships, than of Tilling the Land with Ploughs; they bestow the utmost of their Skill, learnedly, to prevent the natural Use of all the Elements for Destruction of their own Species, by the bloody Art of War. Some waste their whole Lives in studying how to arm Death with new Engines of Horror, and inventing an infinite Variety of Slaughter; but think it beneath Men of Learning (who only are capable of doing it) to employ their learned Labours in the Invention of new (or even improving the old) Instruments for increasing of Bread."

CHAPTER III.

TILLING THE LAND.

THE one fundamental labor of agriculture is the stirring and mixing of the soil. The effects of this simple practice are most numerous, complex and far-reaching, and the problems associated with it seem to be beyond the comprehension of most farmers. It is, therefore, important that the man who is intending to gain any satisfaction in farming should begin his study and thinking at the handles of the plow, for this point is the very threshold of agriculture. "In general, the texture of lands can be improved by three means,—by judicious plowing and tillage, by the incorporation of humus, and by the use of underdrains.* The value of simple tillage or fining of the land as a means of increasing its productivity was first clearly set forth in 1733 by Jethro Tull, in his 'New Horse Hoeing Husbandry.' The premises upon which Tull founded his system are erroneous. He supposed that plant roots actually take in or absorb the fine particles of the earth, and, therefore, the finer and more numerous these particles are, the more luxuriantly the plant will grow. His system of tillage, however, was correct, and his experiments and writings have had a most profound

*See Cover Crops and Liming, pages 253 and 305.

influence. If only one book of all the thousands which have been written on agriculture and rural affairs were to be preserved to future generations, I should want that honor conferred upon Tull's 'Horse Hoeing Husbandry.' It marked the beginning of the modern application of scientific methods to agriculture, and promulgated a system of treatment of the land which, in its essential principles, is now accepted by every good farmer, and the appreciation of which must increase to the end of time. These discursive remarks will, I hope, emphasize the importance which simple tillage holds in agricultural practice."*

GENERAL REMARKS ON PLOWING.

The land produces abundantly if left to itself, and grows steadily more fertile; then why should it be plowed? We shall find many reasons, if the subject is carefully analyzed. Nature, without the assistance of man, produces but few fruits and tubers of a character suited to the exacting wants of civilized man. Her only effort is to perpetuate the most suitable species, and since there is a constant warfare for the possession of the soil, vastly more plants are usually present than have opportunity for the highest development of these secondary or incidental features; hence the parts which, under domestication, become edible are woody, inedible, bitter, or wanting in flavor. A large

*Bailey, "The Texture of the Soil," Bull. 119, Cornell Exp. Sta. 411.

object in plowing is, therefore, primarily to destroy plants. If the plants are large, they are removed or burned, in order that the plow may have opportunity to do its work. The plow that fails to bury ordinary plants deep enough so that subsequent tillage is not obstructed, does not accomplish all that it should. All of the objects which may be secured by plowing are seldom or never kept in view; hence in America it is the least understood and most imperfectly performed of any operation of preparing the land for crops. It is still worse in Europe. The Englishman does little more than two things with the plow,—inverts the furrow, and makes it straight.

One of the chief objects of plowing is to pulverize the soil. The plow may invert it in the most perfect manner and bury surface vegetation, but if it fails to do the greater part of the fining of the soil as well and leaves it in such a condition that the harrow and cultivator cannot complete the work in the cheapest and best manner, it is seriously defective. Since plowing is a slow and expensive operation, and the plow is by far the best implement that has been devised for moving and inverting the soil, for destroying plants, and preparing the land for surface tillage, and for loosening and pulverizing it, its efficiency and the power required to plow become of prime importance.

Since only 10 per cent of the energy required to do the plowing is used by the action of the moldboard even with those having a fairly short twist, it

is economy to break and disintegrate the furrow-slice to the greatest possible degree by as bold and overhanging a moldboard as possible, considering the character of the land. "About 35 per cent of the power necessary to plow is used up by the friction due to the weight of the plow, and 55 per cent by severing the furrow-slice and the friction of the land-side."* If, after having done nine-tenths of the work, the plow allows the furrow-slice to escape without the greatest possible amount of disintegration, great loss is sustained because the bolder and more efficient moldboard may add 2 or 3 per cent to the draft. To effect the greatest amount of disintegration of the furrow-slice, the jointer or skim plow (see page 67) should be attached, even when plowing stubble land. It should be set deep enough to break up the tenacity of the furrow and to prevent it from kinking. Even tenacious sod can be successfully handled by the bold moldboard, provided the jointer is of the right shape and set deep enough. On very tenacious or stony land, the jointer cannot be used with success, but happily, stony land is not tenacious. The proper use of it also prevents the furrow-slice from turning over too flat, and leaves the land in a corrugated condition, which allows the implements of surface tillage to take hold of the crests of the furrows, and break and fine them without disturbing the sod. In the spring, this

*J. Stanton Gould, Utica, N. Y., Plow Trial, 1867. Leroy Anderson, B.S., found in extended experiments made at Cornell University, 1896, that 55 per cent of the total draft is consumed in cutting the furrow-slice, 12 per cent in turning it, and 33 per cent by the friction of the sole and land-side.

method permits the land to absorb heat and to part with excess of moisture. It also buries all surface matter so that subsequent tillage is not obstructed. In fall plowing, beneficial results will be secured if the land is allowed to remain corrugated. Inverting and fining the soil is at best a tedious and ex-

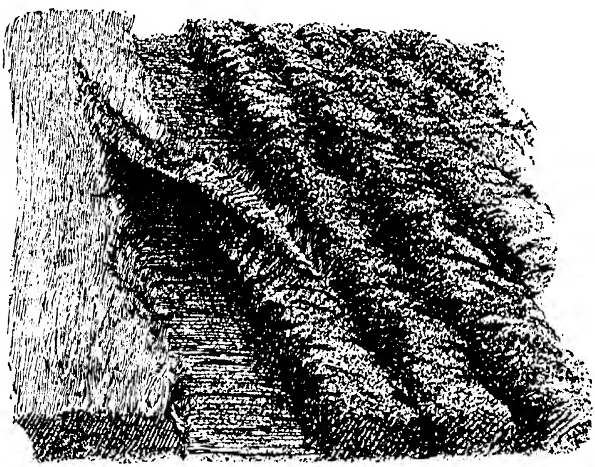

Fig. 16. The complete inversion of the furrow-slice.

pensive process, but the jointer, intelligently used, is the most effective attachment that has ever been invented for accomplishing these specific results, and the more general use of it cannot be too strongly urged.

The three accompanying graphic illustrations will make these matters plain. Fig. 16 shows the furrow-

slice laid too flat, and left with the soil very little disturbed by the action of the moldboard. Plowing similar to this used to take the premiums at the plowing matches held at the fairs over the bet-

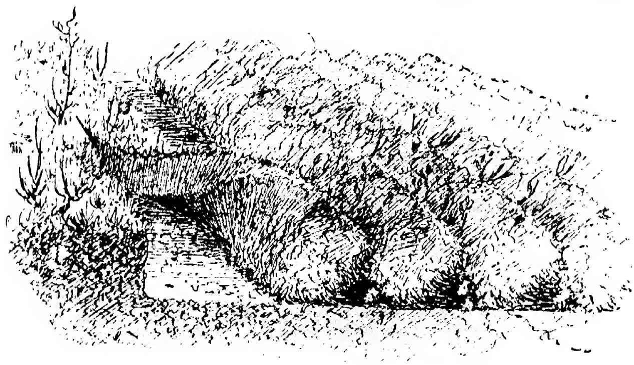

Fig. 17. The furrows standing nearly edgewise.

ter plowing, as shown in Figs. 17 and 18. Fig. 17 is from a photograph of sod land plowed with a coulter attachment and a fairly bold moldboard. The land is moderately well pulverized for one operation, and is left in a fairly good condition for efficient action of the implements of surface tillage, but the plants have not been fully turned under. Fig. 18 is from a like drawing of land plowed with the same type of plow and jointer attachment, but with a somewhat bolder moldboard, which left the surface better pulverized, necessitating less surface tillage than in the former case, and the plants are all buried.

In rare cases it may be best to leave the furrow imperfectly fined and at a somewhat acute angle, as when clayey soils are plowed in the fall for spring crops, as such kind of plowing allows the water to descend and the frost to act upon the soil most energetically. The land might then become warmer and drier in early spring than it would if plowed as in Fig. 18, while the tendency to puddle would be reduced to a minimum. Small changes in the lines of the moldboard, even though scarcely perceptible without accurate measurements, produce widely different results.

The surface tillage which may be necessary to finish fitting the land should be kept prominently in view when plowing. The manner of plowing

Fig. 18. Ideal plowing.

sandy and friable lands matters little so far as the total cost of the whole season's tillage is concerned, but on tenacious soils the plowing often represents

not more than one-third to one-fifth of the cost of suitably preparing the first eight inches of the surface for some kinds of plants. If a tenacious soil covered with a tough sod be plowed with the help of a colter attachment, and the furrow-slice be laid nearly flat, it is nearly impossible to fit the land well until the sod has rotted and the land has been replowed.

In England, planting is seldom done until a deep, mellow seed-bed is secured, no matter how stubborn the soil. The subsequent tillage often costs far more than the plowing. The added labor is necessary, in part, because the colter is used instead of the jointer, and in part because the furrows are laid nearly or quite flat. Plowing is poor that fails to do the greater part of the rough pulverizing, and to leave the surface in the best possible condition for the effective use of the implements which are to follow. This can certainly be done without sacrificing any of the other benefits which should be secured by plowing.

The old couplet

> "He that by the plow would thrive,
> Himself must either hold or drive,"

has become obsolete. May not the following be substituted for it?—

> He that would good plowing view,
> Should think what else is left to do.

Inverting the soil sometimes results in positive injury to the succeeding crop; when, for example, the

land has been occupied by deep-rooted plants, that had been treated to thorough and continuous surface inter-tillage* during the greater part of the growing season, as in potato cultivation. The cultivation which is necessary to keep the weeds in check unlocks the plant-food near the surface. If the plants feed at considerable depth, as the potato does, it is evident that the soil does not need inverting, unless it is necessary to improve its physical condition. It is also evident that the land should be deeply plowed and most thoroughly prepared prior to being occupied by deep-feeding plants. Except on light lands, where all plants are likely to root at considerable distances from the surface, a fairly complete inversion of the soil is desirable if the previous crop has been a shallow feeder, because the readily available plant-food near the surface has been somewhat exhausted, and hence new provision should be made for the coming crop.

The more complete the inversion of stubble land the better. Two kinds of plows, one for stubble and one for sod land, are needed, if the work is to be done in the best manner. While this necessitates additional expenditure for implements, the more efficient work and saving of subsequent tillage fully compensate for it.

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*"Intercultural tillage" is a term proposed by Sturtevant to designate tillage between plants in distinction to that which is performed only when the ground is bare of plants (as in the sowed crops). See Conn. Board of Agric. xi. 190 (1877-8); also, an editorial in Gard. Chron. May 28, 1887. As *tillage* is a better word than *culture* to designate the stirring of the land, "inter-tillage" has been used in this book to designate tillage between the plants—that is, ordinary cultivating, hoeing, and the like.—L. H. B.

In addition to improving the physical conditions of the soil, plowing gives opportunity for weathering, which not only unlocks the fertility of the soil brought up by the plow, but often materially assists in fining it. Unless abundant fertility is present, or there is readily decomposable vegetable matter, as in clover sod, planting would better not follow the plowing closely, as time and surface tillage tend to unlock the inert fertility brought to the surface by the plow. No positive rule can be given for treatment of soils, as climate, crop and conditions vary greatly. If experience shows that turning the land over is advantageous, then it should be done thoroughly, as in many cases great benefit will be derived from so fining and compacting the seed-bed that capillary attraction can bring moisture from below, thereby making it possible for the young plants to avail themselves quickly of the nourishment provided.

Sometimes it is easy to prepare a seed-bed of one or two inches without plowing, and the young plants may start off vigorously, but if the physical condition of the sub-surface soil is bad, capillarity feeble, and available plant-food deficient, the harvest will be disappointing. If the surface is hard and difficult to loosen, as is sometimes the case on fall-plowed land, and when heavy, dashing rains have run the soil together, it is usually best to replow it, so that proper opportunity may be given for surface tillage.

Ever since summer fallows have gone out of fash-

ion, it has been hard to convince the farmer that more than one plowing may be required to bring the land into proper tilth. Because of this prejudice against plowing more than once, a varied assortment of implements for fining the soil has been put on the market. Some of these implements are good, some bad, but few of them are necessary if the plowing has been well done and underdrains have performed their legitimate work. Formerly the land was often plowed five or six times; now the pendulum has swung to the other extreme. The slow, laborious work of plowing with two light horses and a single plow, still in vogue in many states, is dreaded, and justly so; consequently the attempt is made to prepare the ground by "scratching it." If some of the western farmer's methods could be adopted on large, level fields, and six or eight large, strong horses harnessed to a gang-plow, the objects sought might be attained at the lowest cost.

A good plow is capable of accomplishing many results in varied directions, and one not to be overlooked is that of performing the pioneer work of breaking up intractable land while preparing it in the best manner for the efficient action of the implements which follow. We are inclined to extol the progressive spirit of the American farmer, and speak slightingly of some of the crude and laborious methods sometimes seen in foreign countries; yet in most parts of the United States the plowing is seldom seven inches deep, and the plowing team rarely exceeds one or two light horses or mules, while the

sugar planter of the benighted Hawaiian Islands uses a double gang of from four to six plows, easily handling furrows eighteen to twenty inches broad and fourteen to sixteen inches deep, and one or two great steam engines take the place of the "cotton mule" of the south and the light team of the north.

SOME SPECIFIC RESULTS OF PLOWING.

Effects of plowing on soil moisture.—Deep plowing assists the downward passage of water. Sometimes the soil is of so close a texture that water passes but slowly to the subsoil, the land becomes puddled, cold and sour, and when broken up is difficult to bring into good tilth. In such cases underdrains are necessary in order to reap the highest results. Better prevent the locking up of plant-food and the formation of clods by underdraining once for all, than go to the expense of breaking clods whenever the land is tilled. When circumstances make it inadvisable to tile the land at once, much may be done with the plow to facilitate percolation.

In theory, all water falling on the land should be made to percolate through it. Practically, this is impossible, and, since it is far better to have the water carried away over the land than to have it stand upon the land, the practice of plowing in wide lands, with dead-furrows falling in the same place for a time, is to be recommended when there is only slight danger of washing. (See "How to plow," page 90.) Removing surplus water from the

surface prevents puddling to some extent, and thus indirectly assists the downward passage of the water which is not directly carried off, thereby keeping the land loose enough for the ready passage of the water that falls at the beginning of showers, and also assisting in arresting and preserving the ammonia which the rain-water contains. This percolation of rain-water not only conserves plant-food, but improves the physical condition of the land. Surface drainage is promoted if the depressions left by the drill or harrow at the time of sowing are at right angles to the dead-furrows, as they form miniature channels which quickly lead the water away. Clay lands that are submerged for a time are affected more by drought than those which are not submerged, and hence the contour of the land should be so shaped by the plow as to assist surface drainage.

Wherever percolation is difficult, comparatively shallow plowing should be done in early spring, and deeper plowing in midsummer and autumn, in order to prevent the formation of a hard-pan. If plowing is continued at one depth for several seasons, the pressure of the implement and the trampling of the horses in time solidify the bottom of the furrow; but if the plowing is shallow in the spring and deep in the summer and fall, the objectionable hard-pan will be largely prevented. This is especially true where the winter frosts assist the downward passage of water by their action on the subsoil. Since frequent and deep plowing materially assists percolation, we have another reason for making a careful study

of the plow as a factor in effecting increased production and fertility.

While subsoiling may clearly assist the downward passage of water, the expense is so great, and the work has to be so frequently repeated, that it has nearly gone out of practice. If the depth of the furrow were increased a little from year to year, changing it in time from six to ten inches, percolation would not only be increased, but other beneficial results would follow. If the little plow, turning a furrow of only nine or ten inches in width and six inches in depth, could be exchanged for a plow capable of handling a furrow sixteen by ten inches, and the two 900-pound horses replaced by three horses of 1,200 pounds each, the necessity of sub-soiling would be largely obviated, and the cost of plowing would be diminished rather than increased, wherever the fields are large and fairly level. The larger team could get through three acres while the smaller is getting through two, and thus by adding one-half more to the daily cost of the team without any increased expense for plowman, half as many more acres could be turned. While the larger plow would do better work in many respects, it would especially assist percolation, increase root pasturage, and enlarge the moisture-storing capacity of the soil. In the past it was necessary to turn only narrow furrows, because the imperfect plows could not pulverize wide ones. With the improved plow, narrow furrows are no longer necessary.

Nearly all cultivated plants get their chief sup-

ply of moisture from the soil, and this fact should be kept constantly in view in plowing and fitting the land. The part which is played by the plow in assisting moisture to rise by capillarity to the rootlets of the plant, and in modifying the evaporation of water from the surface of the land, should be thoroughly understood. If the soil is very porous, the air circulating through it carries off a large amount of moisture; if too compact, the interstices in it would be so largely closed that capillarity would be weak. In neither case will the best conditions be obtained. The aim should be to secure those physical conditions which will to the greatest extent promote capillarity while securing other desired objects. To accomplish this, the soil must first be made fine and then moderately compacted. Here again, the plow plays a most important part, for in order to fine and solidify the soil, the earth must first be lifted so that the inert mass may be twisted and broken up into small particles, when it may be further fined and compacted by other implements of tillage, and by the tramping of the horses. Water tends not only to rise, but to diffuse itself through the land, moving from the moister to the drier parts, and every opportunity should be given for it to do so, *until it gets near the surface, where it should be arrested*, unless one object of the plowing has been to dry the land.

Some soils are so porous that deep plowing works a positive injury, unless care is taken to thoroughly compact the soil before it parts with its

moisture. Notwithstanding this, it is no uncommon thing to see sandy, clay, dry and wet lands plowed and treated alike. (Consult Chapter IV.)

Drying and warming the land.—In the spring it is often as necessary to dry the land as to conserve moisture. In some climates it may be necessary to plow with a view to accomplishing both objects in a single season. If the pores of the soil have been sealed up by heavy rains, it may be best to plow in order to hasten the time of planting, and to give opportunity for rapid evaporation, even though the land may be somewhat too damp for the best working of the soil. If the weather is cloudy and the surface fitting is done at the right time, better results will follow such early plowing than if the land is left to slowly dry and form a stubborn mass before it is plowed. If the land is damp, the plowing should be shallow, the surface left rough, and as much breaking up of the furrow-slice as possible should be done by the jointer and mold-board, in order to avoid locking up plant-food by partial puddling of the sticky earth.

With some crops, as corn, warmth in the early spring plays an important part. In such cases early and shallow plowing is valuable, because it permits the rays of the sun to increase the temperature of the soil, thereby advancing seed-time. In some localities and in some soils, early, shallow plowing is not necessary. What has been said is not to be taken as advocacy of the plowing of heavy lands while wet; it applies only to emergencies, as when

the spring is wet and cold, and a choice must be made between no crop and only a moderate one. In the case of inter-tilled crops, if the land is dried and warmed by early plowing, planting can be done at the proper season, and opportunity secured to reduce the stubbornness of the seed-bed by after tillage.

Forming a hard-pan.—Porous soils, which allow the water to escape too rapidly, are improved if the plowing is so carried on as to form something of a hard-pan at depths suited to the character of the land, the climate, and the plants to be grown. If the plants are deep-rooted, the solidification should be some eight to ten inches from the surface; for shallow-rooted plants, it may be higher. By always plowing at one depth and when the land is slightly wet, too rapid filtration may be somewhat checked and capillarity increased, while in heavy lands the aim should be to prevent the formation of a hard-pan by occasional deep plowing. Just the reverse of this may often be desirable in light lands, as in some parts of New Jersey, where excellent crops are produced from year to year, though the plowing is seldom more than four inches deep, and is nearly uniform from season to season.

Storage capacity of the soil.—Soils vary so much in weight and capacity to hold moisture, yet remaining arable and in good physical condition, that no accurate statement can be made as to their power to take up or to hold moisture. An acre of average soil, one foot deep, when in an arable condition as to dryness, is estimated to weigh 1,800 tons. An inch of

rainfall brings to each acre 113 7-16 tons of water. Soils may contain from 20 to 25 per cent of water, and yet be not too moist for cultivation; yet plants are able to maintain themselves and grow when the soil contains but 6 to 8 per cent of moisture. If an acre of soil one foot deep weighs 1,800 tons when it contains 20 per cent of moisture, it will weigh 1,557 tons when it contains but 7½ per cent of moisture. Two inches of rainfall might be taken up by the first foot of soil in the latter case, provided the soil had been well fined and a little time given for the water to diffuse through it, and yet remain in good condition for plowing, for it would contain but a little over 20 per cent of water. The above estimate takes no account of the water which passes below one foot, which must be considerable when the rains are abundant, although the soil below may be tenacious. These figures, based partly on ascertained facts and partly on estimates, need not lead the reader astray if properly applied to the conditions which surround him.

If the plowing is but four inches deep, and the computation is made on the same basis as before,—that is, 7½ per cent of water present in the soil,—and a rainfall of but one inch be added, the surface land will contain 23.8 per cent of water, and may be too wet for cultivation; but if, as before, two inches of rain should fall, there will be present 35.3 per cent of water, allowing, as before, that none of it has passed below the hard-pan formed by the shallow plowing.

In order to still further emphasize the need of deep tillage to form a reservoir for the storage of moisture, let it be supposed that the soil is in a fine, arable condition as to moisture, and contains 15 per cent of water; if one inch of rain should fall upon the deeply tilled land, the soil would then contain 21 per cent of water, but if it should fall upon the shallow plowed land it would contain over 26 per cent. The case is still worse if two inches of rain should fall, for in the former case the land would contain 28.9 per cent of water, and in the latter 35.7 per cent, an amount which, in soil not full of vegetable matter, would cause it to move bodily toward the lower levels, even were the natural inclination slight.

The damage from water held near the surface does not end in the loss suffered in the growth of the plant and work delayed, for the saturation of the surface soil results in sealing up its pores, thereby destroying the benefits secured by fine tilth, and additional labor will then be required to bring the land again into good condition.

Underdrains and deep and thorough plowing not only diminish the tendency of clay lands to run together, but also increase the storage capacity of the soil, and, since the moisture in the soil is all likely to be wanted some time during the growing season, the more that can be stored up without doing injury the better. It has already been shown, in part, how to enlarge the storage capacity of the soil by the use of the plow, but there are many other factors

which may be used in conjunction with the plow to perfect its work.

Aëration promoted by plowing.—If the soil is compact and the interstices filled with free water or silt, it will not contain enough air for best results, and therefore plowing for the purpose of letting the air enter the ground, as well as to promote drainage and absorption of moisture, may be advantageous. The roots of plants, like fishes, require air, and although they require only a little, that little is necessary to their life and growth. The soil always contains some air, but it may easily happen that there is too much near the surface and too little below. In the first instance, too free movement of the air in the soil would rob the seeds of moisture, and they would fail to germinate and grow. If there were a suitable amount of air in the surface soil and a lack of it below, seeds might germinate freely, but the subsequent growth would be hindered. It will thus be seen how necessary it is to plow deep in order that the land may be converted into a vast reservoir for the storage of air and moisture in the right proportions.

Although little can be done to prevent the rain from entering the soil in too great quantities, yet by intelligent tillage the amount of air in the soil may be largely controlled. Aëration not only promotes plant growth but also sets free plant-food, for upon aëration both chemical and physical action largely depend. Thorough aëration of the land can be accomplished only by deep tillage, which may result

at first in too great aëration and, hence, loss of moisture; if so, the compacting and fining of the land by surface tillage should be done immediately or soon after the plowing.

It may seem that too much detail has been entered into here, but it should be remembered that it is the common practice to plow the entire field, even in dry weather, before anything is done to smooth and compact the loose soil, through which, if not quickly compacted, the hot, dry air circulates freely, and robs the land of needed moisture. After a portion of the field has been plowed it should be fitted before the surface dries out. In the fitting, the sub-surface soil is compacted; this promotes capillary attraction, and a surface earth-mulch of two or three inches is secured, which serves to diminish evaporation. No amount of fertility can produce the results desired if, through carelessness or ignorance, the conditions are ignored that are necessary for the passing of nourishment from the soil to the plant.

Nitrification promoted by plowing.—As has been shown in Chapter I., the soil contains large amounts of plant-food of which usually only a small fraction is immediately available, and therefore one of the objects of plowing is to promote nitrification, or the changing of potential nitrogen into available nitrogen. For the cereals and other nitrogen-consuming plants, the aim should be not simply to furnish them with a full supply of food, but to furnish the nitrogen, especially during the early stages of their growth when they most require it. If by the stim-

ulating influence of nitrogen the plant can be made to enlarge its root-system when young, it will be able to respond to the larger demands which will be made upon it at the time of perfecting its seed. But so much nitrogen may be present as to over-stimulate the vegetative at the expense of the reproductive or seed-producing system, and to cause the plant to grow too large and porous, when it will be likely to lodge or be amenable to the attacks of fungous diseases. Little damage, however, may be apprehended from a surfeit of nitrogen caused by tillage alone, even on new land. In the effort to secure available nitrogen for the plant by means of the plow and associated implements, care should be taken to determine whether it is more economical to utilize that already in the soil by extra labor, or to obtain it through leguminous plants or from outside sources.

In order to promote active nitrification, warmth, moisture and air must be present in suitable quantities and proportions. Moreover, nitrification goes on far more actively in the dark than in the light. One of the objects of plowing should be to bring about the best conditions, for if they are faulty, nitrification may be feeble or entirely arrested. Considering that nitrogen is the most expensive of the commercial plant-foods when purchased, the reader will at once see the wisdom of economizing home resources to the utmost.

It should be said, in passing, that thorough plowing liberates mineral matter as well as nitrogen, and increases production in various other ways. It divides

the particles of earth, presents new surfaces to the action of the roots, and hastens chemical changes.

Physical conditions improved by plowing.—Plants may be said to travel towards their food, for in poor soils they form attenuated roots, with few fibers, until soil containing more abundant nourishment is reached, where they develop an abundance of feeding rootlets. It may also be said that the food must be brought to the plant, for if the soil that contains plant-food is not brought into intimate and close contact with the roots, the plant is not nourished. If the physical conditions of the soil are bad, necessarily the food conditions are bad also, as the action of the forces which prepare the food is hindered. Good physical conditions presuppose that the plow and other implements have brought the soil into good tilth, and that in accomplishing this, nourishment for the plant has incidentally been made available. Aside from all this, the physical condition alone has marked effects on moisture and root-growth, and hence on the welfare of the plant, for the roots penetrate hard, dry soil with difficulty. On the other hand, roots cannot live in very open soil unless water is abundant and constant,—conditions not usually present in the growing season.

Some plants are more likely to escape the vicissitudes of our erratic climate, if induced by good physical conditions of the soil to form roots at some distance from, instead of near to, the surface; while others, as winter wheat, do best if the fall feeding-roots form within two or three inches of the surface;

hence air, moisture and nourishment should be associated in the best proportions and at the right distance from the surface.

Plowing to bring fertility to the surface.—When water passes down through the soil it carries some fertility with it. If it can then be made to return, it should, in part, at least, restore to the surface soil what would otherwise have been left inert in the sub-soil. Observant farmers are often heard to remark, during a dry season, that the following season will be fruitful, as land during a drought becomes richer. So far as the surface soil is concerned, this is true, for the water which passes from the subsoil up to the surface by capillarity carries with it some plant-food, the larger part of which is nitrogen. A part of the water thus brought near the surface evaporates, and leaves behind what plant-food it held in solution. The alkali lands of the plains might be cited to show the great activity of capillarity in bringing soluble material to the surface. By irrigation the deleterious salts of these lands are washed out, or rather down, and the soil becomes fruitful, but if the land is not kept irrigated the salts again come to the surface and kill the plants. Hilgard, in his report on alkali lands,* says: "The most obvious remedy for this evil is, of course, the leaching out of the injurious salts by ditching and flooding, or, if possible, by underdraining. This method is habitually resorted to in sea-coast marshes, near the

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* "Alkali Lands, Irrigation and Drainage." Appendix to Rept. Cal. Exp. Sta. for 1890, p. 27.

mouths of rivers, after the salt water has been excluded by embankments. * * * When the alkali is not very abundant nor very noxious, frequent and deep tillage may afford all the relief needed. Beyond question the damage done by alkali, in at least nine cases out of ten, is due to accumulation at or near the surface. * * * More than half of the alkali land in this state that the people are afraid to touch requires no other remedy than thorough, deep tillage, maintained at all times." I cannot forbear quoting entire his illustration, to show how hard and soft surface soils affect moisture: "The dense crust absorbs water much more powerfully than does the loose soil beneath. This moisture is forcibly drawn from the latter into the surface crust, and there evaporates quickly under the influence of the air and sunshine, hardening the crust more and more, and accumulating therein an increasing amount of alkali. To illustrate this, imagine a sponge, representing the loose soil, to be saturated with water, and a hard, burnt brick, representing the crust, to be laid upon it; the brick will take all the water from the sponge. Yet if the brick be soaked in water and the sponge pressed on it, the sponge, representing the well-tilled soil, will not take up a particle of moisture."

If the plow and the dry earth-mulch be so used as to promote capillarity, they will indirectly assist in bringing fertility within reach of the plants. Thorough tillage tends to multiply rootlets. Plants which have numerous roots are capable of taking up more nourishment than those which have few,

consequently the multiplication of roots is desirable, except in rare instances when the plants make such rapid growth that they fail to fruit satisfactorily. The root-pruning of plants, so largely advocated some years since, has gone out of practice, and, instead, the multiplication and preservation of them, especially the smaller ones, is now in most cases held to be desirable. Plowing not only promotes available fertility, but also increases the area in which nourishment may be found, and the plant responds to its environment by sending out feeders in all directions. However, should the conditions recommended prevent as early and full fruiting as desired, it is wiser to hasten it by withholding nitrogenous manures and fertilizers than to do so by neglecting or mutilating the roots.

Plowing to bury trash.—The object of plowing may often be chiefly to bury trash. All dead and living plants and coarse manures should be so perfectly covered by the furrow that the harrow and cultivator will not disturb them, or become obstructed. If the furrow be narrow and shallow, this cannot be satisfactorily done. It is true that there are cases in which a shallow furrow is desirable, but a narrow furrow may be avoided if the plow has the proper form. A chain attached to the beam of the plow and the end of the double-tree will greatly assist in burying tall plants, especially if the jointer can be used in connection with it. Coarse manures may be raked into the furrow in order to completely bury them, but with suitable plows and attachments

this expensive method of accomplishing so simple an operation is not necessary. (See "How to plow," page 90.)

If the vegetable matter is buried at some distance from the surface, where it will be kept constantly moist, it decomposes more rapidly than if left to dry on or near the surface. Coarse vegetable matter used to form a mulch, should be spread upon the land after the cultivation has been completed. Vegetable matter plowed under may warm the soil, and furnish nourishment for the plants after what has been set free by tillage has been largely exhausted.

If one of the objects of plowing is to bury trash, it can be accomplished in no other way so well as with a strong team and a large, fully equipped plow.

TIMES AND METHODS OF PLOWING.

When to plow.—Land should be plowed when in a bad physical condition, even though the surface soil contains more plant nourishment than the subsurface does, for good physical conditions are quite as necessary, perhaps more necessary, than an abundance of available plant-food. Whenever it is found that it is difficult to set free plant-food and form a satisfactory seed-bed by surface tillage, then the land should be plowed, notwithstanding the additional expense.

Climatic conditions, together with the character of the land and crop to be raised, must determine to a large extent whether the plowing would better be

done in fall or spring. Clay lands in some cases may be greatly benefited if thrown into high ridges in the fall, so that the water may escape, and weathering may destroy the tenacity of the soil and liberate mineral matter. In corn stubble, where there is little danger of washing, a large, deep furrow drawn through each row works wonders, and is usually more efficacious in making the land fine and "early" than if the entire area is broken up, for in the latter case the soil is likely to run together and become hard and difficult to fit in the spring. Other "open land" than corn stubble may be successfully treated, as the winter approaches, in much the same way, by plowing one furrow and skipping nearly two; but in no case should two furrows be turned together, for this results in such high and broad ridges that they are not easily leveled by the harrow before replowing in the spring. If but single furrows are thrown up instead of double ones, they may be easily leveled by chaining a scantling crosswise under the front end of the harrow and driving lengthwise of the furrows. The treatment advised above, as well as that which follows, may result in liberating much plant-food, and in so improving the physical conditions of the soil as to make it possible for plants to avail themselves of it. It is true that all this implies additional labor, but if soils that are cold, wet and hard to fit in the spring can be made friable, and the time of sowing advanced, may not the fall plowing, in the outcome, be advantageous? With rare exceptions, autumn plowing should be done

early, and while the ground is fairly dry. The work should be performed when there is most leisure, unless there are compensating advantages to be gained by deferring it, as the cost is less and the work is likely to be better done. Early fall plowing is usually beneficial, even though shallow replowing is necessary in the spring, and a fall "catch crop" has to be sown on light lands to prevent them from leaching during the rainy months. In the great wheat districts of the northwest, where the winters are dry and cold, fall plowing should be and is the common practice. Weathering of the soil is a more economical method of setting free plant-food than surface tillage, and when certain conditions are present, as hard freezing and light rains, and when a goodly interval comes between the harvesting of one crop and the planting of the next, it can be practiced successfully. If the land is infested with wire-worms late fall plowing will destroy many of them.*

Spring plowing is best done early, if the soil is in proper condition, and it may be done even when slightly too wet, provided some little freezing follows. Since early sowing is of prime importance if plump grain and bright straw are desired and rust is to be prevented, some risk may be taken in this direction. On damp, rich lands, late-sown cereals, especially oats, are likely to suffer from fungous diseases, which result in diminished quantity and impaired quality. Ground intended for the production

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*For the treatment of wire-worms, see Bull. 33, Cornell Exp. Sta.

of maize is improved by early plowing, unless the land is occupied by clover, when it may be wiser to defer the plowing for a time, in order that the clover may make some growth before being turned under. In this case, the gain in the growth of the clover may more than compensate for the plant-food which is liberated by the early plowing and the weathering.

When not to plow.—If a good seed-bed can be prepared easily, and the surface is richer than the sub-surface soil, as in a well-tilled potato field, then the ground may be sown to grain without plowing, more especially if the preceding crop was a deep-rooted one.

When the land is producing a reasonable harvest of hay, and the plants are perennial, it is not well to destroy them and, after laborious effort, harvest those of less value, as not infrequently occurs when timothy sod on clay land is broken up and planted to maize.

It is well understood that it injures land to plow it when wet; it is not so well known that land may be injured by plowing when too dry, for if the soil becomes very dry or dust-like, it is likely to be beaten down and puddled by heavy rains. Land which is designed for fall sowing would best be plowed at least one month before the sowing takes place, as wheat and like cereals love a cool and compacted sub-surface soil.

How to plow.—In midsummer and fall, deep plowing is desirable; in early spring, rather shallow fur-

rows are usually best, as the sub-surface soil is much colder and wetter than the surface soil. These are meant to apply, of course, to the management of land in farm crops, and not necessarily to orchards. Manures and other decaying matter should not be turned under deeply in the spring, for if left near the surface they decay quickly, and the roots of the growing plants are able to feed upon them early in the season. In the spring the land should be "struck out," so that the turning at the ends may be towards the right (or the left with a left-hand plow), that no trampling of the plowed earth may occur. In the early part of the season it is desirable to keep the land loose and light, in order that warmth may be absorbed and moisture evaporated. If there is danger that evaporation will go on too rapidly, the surface tillage of the soil should follow the plowing closely. While the fining and compacting which result from the trampling of the

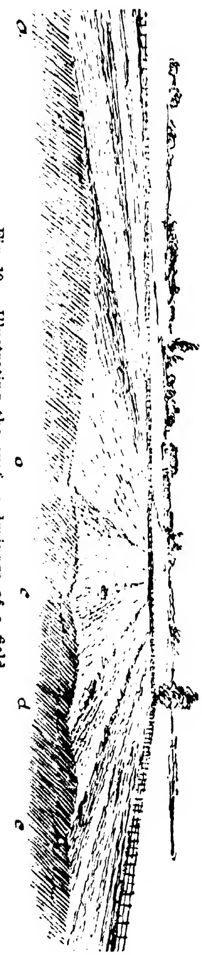

Fig. 19. Illustrating the surface drainage of a field.

horses' feet, when the land is dry, is often desirable if distributed over the field, solidified places, caused by turning at the ends of the lands, are to be avoided in the spring. It has become far too common to leave the field with few or no open furrows; this may do where it is thoroughly drained, or the soil sufficiently porous to allow the water to percolate through the subsoil in a reasonable time, but there are many fields in which the open furrows should not be more than ten to fifteen paces apart. It is not difficult for a skilful plowman to leave the surface in great, gentle swells and in suitable condition for the passage of the harvesting machinery. On clay land, where damage is likely to occur from water standing on the surface, the ridges of the lands may be in the same place for several successive plowings, provided the two furrows of which they are composed are not overlapped, and the ridges are split and thrown back when the land is not in sod, and the open furrows are partly filled by light back-furrows and harrowings. (See "Surface Tillage," page 99).

Plowing "lands" of five to seven paces do not so effectually drain off the surface water of nearly level lands (see Fig. 19) as those of from twenty to twenty-five paces do, because not enough water is carried into any one of the dead-furrows to produce a current sufficient to overcome the obstruction offered by clods and friction.

The open furrows which divide the narrow lands (*c*, *d* and *e*) have stagnant water in them, while

those (*a* and *b*) which divide the wide lands are free from water. Concentration of water tends to move it, division to bring it to rest. A striking illustration of the latter is seen in the cultivated fields of the south, where the cotton ridges are laid nearly at right angles to the steepest incline, thereby preventing washing by too rapid fall and by division. The jetties of the Mississippi may serve to illustrate the principle of increasing flow and scouring by concentration of water. Usually the lighter the soil, the shallower the plowing, except when it has received liberal dressings of barn manures, or has acquired a large amount of vegetable matter from other sources, when the plowing may be done as experience shows will give the most profitable results. In market-gardening, three to five cords of manure are sometimes applied per acre for several consecutive years; the soil will then contain a superabundance of nitrogen and humus, and will retain moisture, and all the rules for plowing light lands may be broken with impunity.

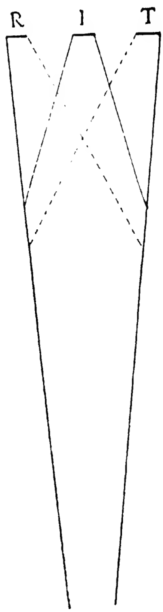

Fig 20. Diagram of proper arrangement of driving lines for three horses

Thorough and deep plowing is most economically performed with a large sulky plow and three or more strong horses, except when the fields are small,

irregular or hilly, when an unmounted plow and two horses may be used to best advantage. Three horses abreast should not be driven with double check-lines, as their mouths soon become sore from the bits being drawn through them by the couplings which connect the horses. Two extra checks, buckled to the double lines just back of where they branch, will allow free motion of the head of each horse without disturbing its mates. Fig. 20 explains the arrangement of the lines, the bits being represented by *R*, *I*, *T*.

Fast-walking, strong horses not only get through with more work, but do better work than slow-walking, light teams do; for, within certain limits, the faster the plow moves the better the pulverization. In stony land, where a slow pace is desired, it is pleasanter to restrain a lively team than to urge a slow one up to a business gait. The team should be able to draw a plow at a rapid walk for nearly five hours consecutively; nine to ten hours of actual work per day is all that should be required. It is bad economy to sit on the plow handles to kill time while the horses are storing energy to proceed. One may know how to plow well but be unable to do so, if furnished with a spider-legged team which has had to spend the greater part of the night in getting its food from sorrel-covered hillsides. On fairly level fields of twenty acres and upward, four to six horses may be used to a gang of two or three plows, and the plowing will be done cheaper and better than by dividing the teams and gang into

three separate outfits, requiring two additional plowmen to operate.

In changing potential into actual plant-food, economy and efficiency both demand larger fields, even if some of the inside fences have to be removed and portable ones substituted for a part of them when needed. The width of the furrow should be slightly greater than the plow can cut, as it is easier and better to tear off two or three inches than to cut it, and this may be done even where Canada thistles are present, as they are injured more by having their heads turned under than by having their roots cut off. The more difficult the land is to cultivate, the more corrugated,—not cloddy,—the plow should leave the surface; this is especially true of land likely to run together during abundant rains.

Six well-broken horses, either two or three abreast, may be driven with a single line, as is done in California; this may also be done with a single three-horse team. When several teams are used together, all but the beam horses may have their double-trees attached to a chain run through the ring of the neck-yoke of the beam team, or each horse may have his traces hooked to the ring in the hames of the horse behind; though this method is the most convenient, it disturbs the true line of draft, and is hard on the necks of the beam horses. If thus attached, the smallest team should be placed at the rear and the largest ahead.

Line of draft in plows.—Both the English and French use longer traces and plow-beams than the

Americans do. The fashion set us by our foreign ancestors would no doubt have been followed if stumpy fields had not taught us that short traces and plow-beams are more convenient. The normal line of draft is at right angles to the plane of the horses' shoulders and in a straight line from the point of greatest resistance through the clevis at the end of the beam to the point at which the traces are attached to the hames.—Horses appear to work easier with short traces, because the line of draft is raised at the hames. If the work is at all severe, this materially helps them to secure a firm footing, while it relieves some of the friction of the sole of the plow. While this holds good with unmounted plows, short traces do not relieve friction when the plow is mounted.

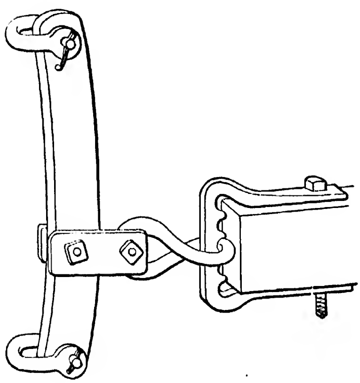

Fig. 21. A handy three-horse evener made of bar iron.

A piece of iron sixteen inches long and five-eighths inch by two inches, pierced with three holes at suitable distances, standing vertically, makes a light, handy three-horse evener. This is shown in Fig. 21. The holes of all eveners should

be placed in line, or they are not eveners. If the center hole is ahead of the end holes, then the weak or stumbling horse that falls behind has the short end of the lever (*b* to *c*, Fig. 22), and must do more

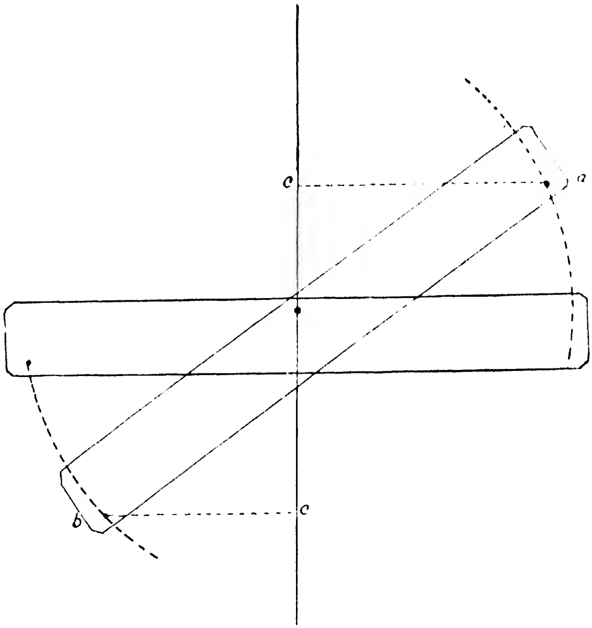

Fig. 22. Diagram showing the mechanics of the evener.

than half of the work before he regains his position. If the evener is furnished with a staple at the rear side in the middle, and the ends with clips, instead of clevises, as is quite common, then the reverse

conditions of those shown in Fig. 22 will be present, and the horse that falls behind will do less than its mate. To obviate all unevenness of an evener, always place the three points of attachment carefully in line.

Narrow furrows have always been recommended, as it was believed that the best plowing could not be done with wide furrows; this was true with the old, imperfect moldboard, but with the improved one good work can be done, even though the furrow be two or three times as wide as it is deep. The wider the furrow within reasonable limits, the cheaper the plowing can be done; the same holds true as to depth, since the power to draw the plow does not increase in the same proportion as does the square of the furrow-slice. If a furrow six inches deep by ten inches wide (sixty square inches) requires 200 pounds of energy, 400 pounds will not be required by one eight inches deep by fifteen inches wide (120 square inches).

Anderson* secured the following results from a trial of drafts of plows:

Depth of furrow.	Aver. width.	Sq. in. in furrow.	Aver. draft.	Draft per sq. in.
7 inches.	12.74 inches.	89.18	353.9 lbs.	3.96 lbs.
10 "	13.46 "	134.6	441.49 "	3.28 "

These results agree in the main with those secured by Prof. J. W. Sanborn, 1888 (Missouri Bulletin 32).

At the Utica Plow Trial, in 1867, the increase was found to be about 10 per cent for each addi-

* Thesis presented to Cornell University by Leroy Anderson, B.S., 1896.

tional inch in depth. When the width varied and the depth was constant, the following results were secured:

Depth of furrow.	Aver. width.	Sq. in. in furrow.	Aver. draft.	Draft per sq. in.
7 inches.	10.9 inches.	76.3	293.95 lbs.	3.85 lbs.
7 "	14.04 "	98.28	363.87 "	3.7 "
7 "	17.74 "	124.18	445.19 "	3.58 "

SURFACE TILLAGE.

The results of surface tillage, like plowing, may be simple or complex. The prime object is usually to form a smooth, fine seed-bed, but unwittingly the other objects secured may be of far more importance than the one sought. Seeds which are small require shallow covering, hence they demand a seed-bed made extremely fine, and which may be compacted with the roller after seeding to prevent too free circulation of air and to bring moisture to the surface; in the case of large seeds, which require deep covering, the surface need be only fine enough to induce capillarity to bring water near the surface. Plants which throw out roots near the surface should receive shallow surface tillage, while those which root deeply may have deep tillage. The aim should be to prevent the water from rising above the earth in which the roots are feeding.

A corrugated surface, produced by deep tillage, may be resorted to for drying the land in extreme cases; hence it is just the reverse of what is desired

in dry weather, as it exposes a larger surface to the action of the wind and sun than a smooth surface does. Surface tillage may be made not only to conserve moisture, but to set free plant-food; if the plants are deep-rooted, they may secure only a small part of the food liberated by tillage. This emphasizes the need of deep plowing and deep surface preparation of the land for all tap-rooted plants; with shallow-rooted ones deep tillage is not so imperative. Too much stress cannot be laid on the necessity of superior surface tillage for the purpose of forming a mulch of fine earth to conserve moisture, and for promoting filtration of water and the easy passage of moisture upwards to the mulch. Whenever heavy rains have produced a crust, it should be broken up by tillage as soon as the land is in a suitable condition, that the earth-mulch may be restored and evaporation arrested. The philosophy of the surface mulch is explained in Chapter IV.

Usually the mulch is not preserved long enough in inter-tilled crops. The best results cannot be reached if the foliage of the plant is not kept healthy and active, and it cannot be kept so without a supply of moisture, especially during the flowering and fruiting period. The yield of inter-tilled crops is greatly increased if the earth-mulch is preserved intact until late in the season.

In the orchards in Sacramento Valley, California, the trees are usually loaded to the earth with fruit, the great, broad, green leaves of one tree touching

those of its neighbor, and yet irrigation is not practiced, though rain seldom falls from the last of April to the first of October. As one sinks to the shoe latchets in the soft, dusty earth of these fruitful lands, he is led to appreciate the power of capillarity to bring moisture to the rootlets, and the efficiency of a deep-earth mulch to conserve it. The winter rains fill the subsoil with water, the deep, dry earth-mulch of four inches or more arrests evaporation, capillary attraction lifts the water from the sub-reservoir to the rootlets and as high as the under surface of the earth-mulch, and thus by scientific treatment of the soil the orchards are carried safely through a drought of five months' duration.

When the object of surface tillage is mainly to destroy weeds and grass, then it should be given before they have become firmly fastened in the soil by their roots, or, still better, before they have appeared above ground. Perennial plants are likely to live through the year and appear the following season in a vigorous condition, if allowed to form leaves a few times during the summer. There are two periods when plants may be most easily destroyed: before they emerge from the ground, and when in blossom.

Spring-toothed implements, or those of a similar character, serve best for destroying annual weeds; the plow, the spade and the mattock are best when hardy perennial weeds are to be eradicated. The scythe, though used largely in lieu of the last-named implements, is never an entire success, for it per-

mits some growth to continue, and the weeds, though weakened, are not killed. Frequently the chief benefit secured by surface tillage in the spring is at first increased warmth; later it may tend to prevent cooling by evaporation. If crops are inter-tilled every ten days, all the benefits to be derived from inter-culture may be expected, as more frequent tillage does little good and tends to arrest growth, as rootlets are broken and the plants bruised unnecessarily. With shallow-rooted plants, as maize, the inter-tillage should be as deep as practicable at first, that the soil may be prepared thoroughly before the roots have entered it, and shallower later on, in order that the rootlets may be disturbed as little as possible. Tillage should not proceed so far as to convert the soil into dust, or it may puddle and bake during and after heavy rains. Inter-cultural tillage is most economically performed by the use of a two-horse team and wheel cultivator.

Implements for surface tilling.—The roller may greatly facilitate the fitting of the land in two ways, by so compacting it that other implements act effectually, and by breaking clods. Rolling after the seeding hastens germination in dry weather, because it increases the capillarity of the soil by compacting it and, therefore, brings moisture to the very surface. In the spring, the rolling of heavy lands will be detrimental if abundant rains should follow, but beneficial if dry weather follows. The roller may be used in many ways to assist, directly or indirectly, in securing the objects sought; viz, liberation

of plant-food, improvement of physical conditions, increasing of capillarity at the surface, hastening germination of small seeds, and preparing a smooth surface. The roller is a useful implement, but it requires good judgment and some experience to know when and where to use it.

Plankers are often more efficacious in fining and filling the interstices of the surface soil than rollers are, for instead of pushing the clods into the soft soil they grind them, and leave the surface smooth and fine for the reception of small seeds.

Harrowing tools may be classified under three general heads: those which tend to press the soil down while fining it, those which tend to lift it up, and those which tend to slice it. Of the first class, the harrow or drag may be cited. Strictly speaking, the harrow may be defined as the implement in which the teeth project so far through the frame that its bars do not level or grind the clods, while in the drag the teeth are short and the bars serve to grind and level the soil. In most cases, the latter implement is to be preferred, since in any case the teeth do not enter the soil but a little way. Long teeth are objectionable, as they tend to clog, and prevent the harrow from doing a part of its legitimate work. There are many reasons why the harrow should be spread over a large surface, the chief of which are that it runs steadier, is less likely to become obstructed, and does not so easily dodge the hard places. It also is more efficient in leveling the inequalities than a compactly built harrow is,

and much ground may be gotten over where only a light harrowing is desired, while in rough ground a half lap may be taken or the ground gone over twice, thus increasing efficiency by attacking the clods from two directions. The common harrow may not only be spread over a large area to ad-

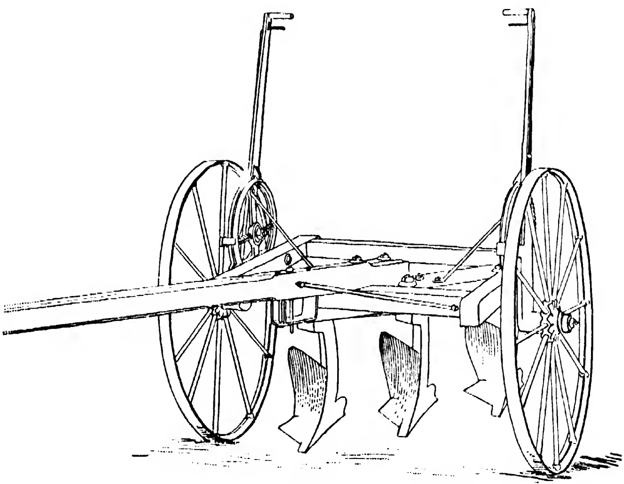

Fig. 23. A good gang-plow for shallow tilling.

vantage, but it is best when made large and heavy. One has only to observe how inefficient the half of a harrow is when used alone, to be convinced that it is economy to use large ones. Those which are mounted on wheels are more efficient than those which are not, as they run more steadily and are more readily managed.

The second class comprises the spring-toothed

harrows, which are really cultivators, and should be classed with them. The action of the third class—as the "Acme"—somewhat resembles that of the plow, since it first cuts and then grinds the soil. The land and the condition in which it is left by the plow vary so widely that it is difficult to foretell which of these classes of implements will be most efficient for the power expended.

Cultivators are of numberless patterns.—In the west the teeth of these implements are usually made with a flat or flattish surface in front, while in the east they usually have a rounded front. The former are by far the most efficient, as they compel one portion of the soil to grind another by the sharp contact necessary to push the soil to the right and left, while the rounded tooth allows the earth to escape with less pulverization. Most cultivators fail to cut and destroy all tough, tap-rooted plants, as Canada thistles and docks. Wherever a gang-plow especially made for shallow tillage can be substituted for them, the work will be more satisfactorily performed. Three small mounted mold-boards, with share attached to each, cutting ten inches wide and three to four inches deep, make a most efficient implement in many cases for preparing a seed-bed. (See Fig. 23.) There are many other implements adapted to local conditions and special crops which may be made to assist in preparing the soil and in liberating fertility.

It is believed that the time is not far distant when wheat, oats and barley, and indeed all grains

that are now broadcasted or drilled, will receive inter-cultural tillage similar to that now given to maize, and this will not be by hand, as in some portions of Europe, but by horse-hoe tillage. It is fully realized that two to three times as much seed is now sown as is necessary to produce a maximum crop, were it not necessary to crowd out and repress the weeds by thick seeding. When too many plants are present they unnecessarily rob the soil of plant-food, and especially of moisture; hence all the plants are dwarfed, and notwithstanding their vast number the yield is, as in wheat, reduced to less than one-half of a moderate crop, and one-third of what might be secured under the most favorable conditions.

The unsatisfactory results secured during the last few years by seeding to grass and clover with one of the cereal crops leads to the conclusion that this practice will sooner or later have to be discontinued. In fact, the practice of plowing and fitting the stubble lands in August, and of sowing grass and clover without an associate crop, has been adopted in many cases. The results reached by this method are entirely satisfactory, as a full crop of hay is secured the following year. Heretofore, the objection to seeding without an associate crop has been urged that one season or crop was lost. Since the lesson of preparing the soil thoroughly and of sowing early has been better learned, this objection has been entirely overcome, so it is probable that on small areas on high-priced land, the yield per acre of wheat and

similar crops will be more than doubled by some method of inter-cultural tillage, and that the practice of early fall seeding to grass and clover without an associate crop will become more and more common.

He who has spent but a single summer toiling long days in the fierce sun, stubbing his toes against the numerous clods and stones while wiping his brow of the sweat and dust will, it is hoped, catch the spirit of this long chapter, in which the aim has been to show how toil may be changed into inspiring and wisely directed work, and how the dull clods of earth may be transformed into joyous life by the least expenditure of physical exertion.

In all this effort, the object should be to more wisely direct the forces of nature, in order that larger and more beneficial results may be secured with the minimum expenditure of human muscle. There are vast dormant energies—animal muscle, steam and water, electricity—which, when well directed, may so greatly ease the burdens of rural life as to make the farm a pleasure, even though the actual cost of the operations may not be reduced. If the introduction of the reaping machine had been of no value in farm economy, the invention would still have been worth the while, because of the mental uplift which it gives the farmer's boy who learns how to manage it.

CHAPTER IV.

CONSERVATION OF MOISTURE.

In the preceding chapters reference has frequently been made to the conservation or saving of moisture, the capillarity of the soil, and the earth-mulch. It will now be profitable to enquire more specifically into these matters. To the careful observer, it is evident that cultivated plants suffer far more from lack of moisture than from lack of nitrogen, phosphoric acid and potash in the soil; that is to say, nearly all soils would respond to tillage in a most satisfactory manner were there an ample supply of moisture for the use of the plants at all times. This is so self-evident that it need not be illustrated or proved. Then, without hesitation or modification, it may be said that the problem of providing a suitable supply of moisture for growing plants should be carefully considered when a study is made of the science and art of agriculture. Tons of farm products lay rotting along the Ohio river a few years since because the water was so low that they could not be carried to the market. Tons of plant-food remain unused and useless in the soil of the farm for lack of moisture to transport the waiting nourishment into the living plants. It can hardly be too strongly empha-

sized that the subject of moisture, how to secure it, how to conserve it, and how to use it, is the one that should receive the most scientific, the most careful and persistent investigation that the farmer is able to give, for without moisture nothing can pass into or out of circulation.

The gist of the whole matter is this: The soil is a sponge, holding water by capillary attraction; in dry weather the moisture passes upward by capillary movement, the water from below taking the place of that which evaporates from the surface; the rate of this upward flow depends greatly upon the compactness or capillary continuity of the soil; if some non-capillary body is placed on the soil, evaporation is checked; this non-capillary body may be a mulch of straw or manure, or better, a mulch of loose dry soil,—the "earth-mulch" of which we have spoken.

If water is allowed to flow off the field and forest unnecessarily when it is abundant, it cannot be returned except by expensive appliances and much labor. In the greater part of the United States it is wiser to store and hold back the moisture in the soil to the point at which, if more were stored, it would be injurious. It has already been shown how the moisture-storage capacity of the soil can be increased without injury to its productive power by deep tillage. Something has also been said incidentally on the conservation of moisture. There are various methods, one or all of which are always at hand, by which both water and moisture may be

saved or economized for the use of growing plants throughout the season.

Shading by cutting off the direct rays of the sun reduces evaporation, and may indirectly slightly increase the capillary action of the soil, thereby enabling it to bring up more moisture from below, and also preventing the excessive evaporation of it from the surface. Brush, leaves, maize stalks, and other refuse material, and even fine earth, act most beneficially when spread thinly on the dry, semi-bare knobs of the grass fields. While it is not advisable to attempt to conserve moisture on any large areas by the use of these materials, yet full success is only secured by making good use of the small things as well as the large ones. Many an unsightly place in the lawn could be improved if a few seeds were sown and the sod covered lightly with fine, rich earth. Many a bare place in the hilly pasture could in like manner be healed, if brush were used to partially shade the land and to prevent the animals from grazing the grass too closely. In all these and similar cases, conserving the moisture may give more satisfactory results, all things considered, than expensive manuring or irrigation.

A light mulch of fine manure on meadow land may not only conserve moisture, but also furnish acceptable plant-food. It can be readily understood that if pasture lands are not fully covered with herbage, there will be unnecessary loss of moisture where the bare spots occur, be they ever so small. Then, to secure the greatest benefit from stored

moisture, the entire surface should be shaded with plants. If there are numerous small bare spots in the pasture, moisture escapes without passing through the plants. If there are too many plants present, there may not be enough moisture for the multitude; if so, the plants fail to make a normal growth, and are dwarfed in size and injured in quality.

The herbage on the ungrazed mowing lands soon becomes tall enough to shade the land, although the plants are or should be less than half as numerous as on the pasture lands. Many permanent meadows have too many plants; most pastures have too few plants. It may be said that a meadow thickly seeded furnishes a larger per cent of leaves to stalk than one only moderately seeded. On the other hand, it may be said that leaves grown in a dense shade are poor in quality, deficient in aromatic oils, and are less valuable than seed-stalks and blossoms grown in the sunlight. One has but to taste an apple from off the lower branch of a tree and one from the sunlit top, to fully appreciate what effect sunshine has on the quality of plants and their fruits. In the pasture, no matter how thick the plants may be, all receive, on account of their diminutive size, sufficient sunshine, yet it is quite possible to have so many plants, even in the pasture, that there may be an undue struggle for moisture and existence.

Mulching on a large scale with coarse manure and refuse material in inter-tilled crops, as berries, orchard trees, and the like, is not to be recommended, for it tends to obstruct tillage, encourages the growth

of weeds, and induces the plants to feed too near the surface, in which case they suffer from drought and severe freezing whenever the mulch is removed or has decayed. The cost of such mulch is so great,

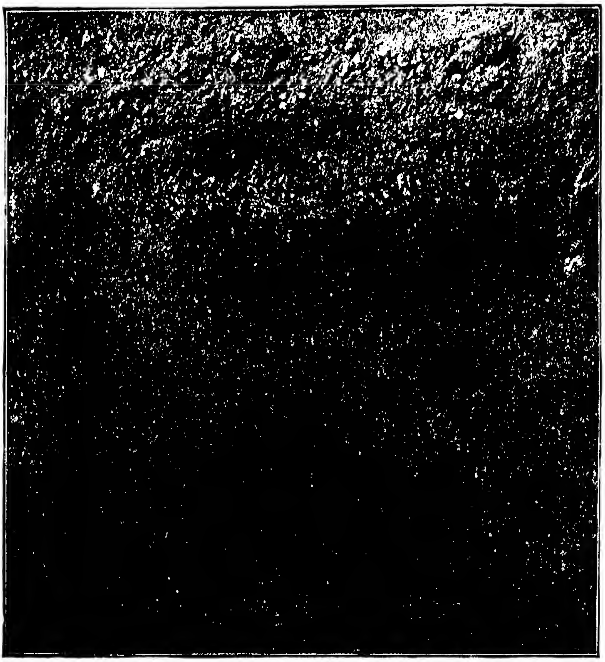

Fig. 24. Photograph of a cross-section of soil, showing the compacted under soil or sub-surface, and the earth-mulch on top.

as compared with one of earth, that it should not be adopted except on areas too diminutive for horse tillage.

Moisture may also be conserved, especially on

light lands, by adding humus, or vegetable matter to the soil, since it increases capillarity and the moisture-storing capacity of the land.

The most satisfactory and universally applicable method of conserving moisture, however, is that of

Fig. 25. Photograph showing a section of soil not fined nor compacted below.

a soft earth-mulch. Fig. 24 represents a deep earth-mulch resting on soil well fined and compacted. Fig. 25 shows a clayey soil freshly plowed, not compacted or fined except at the surface. It is evident that in the second case no moisture can rise by capillarity from the subsoil towards the surface, and

it is also evident that the air may circulate with too much freedom through the plowed soil, and rob it of the moisture which it contained when plowed. Fig. 25 fitly represents the condition of clayey fields which are plowed dry in mid-September, harrowed lightly, sowed to wheat or rye, and rolled. Were it not for the heavy rains during the fall, lands prepared in this way would give more meager results than they do. If rains come early and are abundant, the capillary power of the soil may be partially restored.

It is impossible to state accurately just how compact the sub-surface soil should be, or how deep or how fine the surface, but some general rules and illustrations may help to guide the judgment when deciding these difficult points, which become doubly difficult when applied to various conditions and when widely differing results are desired.

Light and sandy soils have but feeble power to hold moisture and to furnish it to the growing plants. Their power to do this work is increased by a most thorough solidification of the sub-surface soil. As a rule, these are the soils which are solidified the least by tillage, since they can be made fine and smooth and put in an apparently good condition with a minimum amount of tillage. The productive power of this class of lands is increased quite as much by frequent rollings, harrowings and trampings as that of the more tenacious soils is. On all lands which do not run together when wet, no damage, but rather benefit, may be expected from frequent surface tillage. Clayey soils usually require

extra surface tillage to bring them into proper physical condition, but if the soil be dryish the earth-mulch may become so fine, and even dusty, by tillage as to be seriously puddled by dashing or long-continued rains, in which case the moisture will rise to the surface and be dissipated by the heat of the sun. Then, too, it is possible, by too frequent surface tillage when the soil is dry, to so fine the earth as to cause the soil particles to be held in suspension, and they would then pass downwards, and so fill the pores of the land as to arrest capillarity and exclude air, in which case the water would pass off over the surface in wet weather and the land crack in dry weather, both of which conditions are undesirable if moisture is to be stored in the soil. Soils containing an abundance of humus are less likely to be injuriously affected by the conditions mentioned above than those deficient in humus are.

While a deep earth-mulch conserves moisture better than a surface one, yet in some cases the shallow mulch may be most desirable, as in maize culture, when the plants have become large and the roots occupy the soil near the surface. A deeper mulch may be maintained when the deeper-rooted potatoes are grown. In warm climates, the roots of all plants tend to form at lower depths than in cool climates. In sandy or semi-arid districts, the roots of plants tend to avoid the upper strata of the soil. Some plants, as bearing trees, are most fruitful if their growth is somewhat checked during the latter part of the season, and hence the earth-mulch should not

be continued intact during the latter part of the summer and fall, or the trees will have their vegetative energies stimulated at the expense of fruitfulness. The unfruitfulness of some orchards is due to over-stimulation of the vegetative system by a too large supply of nitrogen. Unfruitfulness may also come from a lack of moisture, and hence a lack of nourishment, at critical periods in the life of the tree. It will be seen how intelligent must be the use of the earth-mulch, manures, cover crops and the liberation of moisture and plant-food by systematic tillage, if the highest profitable success is reached.

From the first of July in the south to the middle of August in the north, either crimson or red clover may be sowed to check too rapid growth of orchard trees. This check tends to make the trees develop strong, mature fruit-buds, able to resist adverse conditions. But under certain conditions the nitrogen furnished by the clover, when plowed under the following spring, may so stimulate the vegetative energies as to diminish fruitfulness, and the covering of clover or plant-mulch, which is so beneficial in most cases, may then be injurious. If trees give indication that this is the case, a cover crop of rye should be substituted for the clover, or the clover may be closely pastured in the spring, before it is turned under.

We have seen the danger of continuing the earth-mulch too late in the season in fruit-culture, but the ordinary inter-tilled crops, as maize, are greatly benefited by preserving a mulch intact to

Fig. 26. Late inter-tillage of maize at Cornell University, 1896.

as late a period as possible, since at the end of a period at which the inter-tilled crops are "laid by" they are so far advanced as to preclude over-stimulation of the vegetative system. Since these crops usually lack a full supply of food, and especially a full supply of moisture, during the time of maturing fruit, late, frequent, shallow tillage should be continued, that the plants may have a full supply of nourishment and ample transportation facilities for carrying it to the reproductive organs. Fig. 26 shows the effects of late shallow tillage upon Indian corn.

Most of the potatoes in the general market are insipid and undesirable largely because their normal growth is arrested before they are fully mature. A lack of foliage in the later stages of development, due sometimes to disease, but more commonly to lack of moisture, results in small yields of inferior tubers.

All that has been said of conserving moisture by suitable and timely tillage holds equally true when applied to crops not inter-tilled. Much may be done to so compact or fine or loosen the sub-surface soil and prepare the surface soil as to liberate plant-food, form a reservoir for moisture (not for free water), while securing the most desirable capillary action and the conservation of moisture. To facilitate the saving of moisture, crops such as grass, wheat, oats and the like, may be in part inter-tilled by the use of harrows having numerous short, small teeth. True, only a shallow mulch can be secured, but this is to be preferred to a moisture-wasting crust.

The depth and character of the earth-mulch should be governed by the root habits of the plants, by the species grown, by the character of the soil, by the climate, and by a clear conception of the results desired. Moisture and water play such important parts in the successful growth and development of plants and animals as to compel the most painstaking effort to discover the natural laws which govern their actions and their economic use in husbandry. (This subject is further discussed in Appendix B.)

CHAPTER V.

IRRIGATION AND DRAINAGE.

THE discussion of the means of securing and saving soil moisture naturally suggests the subjects of irrigation and drainage. Whilst these matters are too large for specific treatment here — and both of them are soon to receive special elaboration by other hands — a few remarks upon their general relations to farm-practice may be useful.

IRRIGATION.

If irrigation is carried on in any large way, the initial problems to be solved belong properly to the civil engineer. No farmer, be he ever so well trained in the cultivation of plants and tillage of the soil, can hope to have accurate knowledge or experience in the construction of large reservoirs, the damming of water courses, the digging of canals, and the equitable distribution of water among those who purchase it at a given rate per inch, or amongst the owners of the irrigating plant. Then, too, wherever water is stored or taken out of running streams, serious legal questions often arise; in fact, they are sometimes so serious that special

legislation is necessary, not only to guard the rights of those in the immediate district, but also to guard the rights of those living in adjoining states who would have a moral, if not a legal, right to the use of water which naturally flows through their lands.

It is not the purpose at this place to go into any detailed discussion of the subject of irrigation, but to discuss it in a general way. In the last few years, some interest in irrigation has been awakened in the states lying east of the arid or semi-arid district. A few small areas of land in the humid district have been irrigated with more or less satisfactory results, and in a few rare cases sub-irrigation has been practiced on experimental plats. In all districts where the annual precipitation is fairly abundant, and is not distributed with too great irregularity throughout the various months of the year, irrigation is not likely to be practiced, except on small areas devoted to crops which give or should give a large income per acre. In the areas spoken of, where rain may come at any time, irrigation or flooding of the land at any given time when the soil appears to need moisture may be and usually is just preceding a greater or less precipitation. If, then, the land be filled with water and heavy showers immediately follow, the land will be supersaturated, and the damage done by the superabundant water, due to the irrigation and the rainfall combined, may be far greater than the loss or damage which would have been caused by the too dry condition of land had no irrigation been practiced.

Wherever irrigation is provided for outside of the arid or semi-arid districts, except on porous or light lands, full and ample sub-drainage will have to be provided if the highest results are obtained. The cost of providing the irrigating plant and of thoroughly sub-draining the land combined, would be so great as to preclude profit, except under special conditions and with a few special crops. Then, too, a large portion of the district which has a fairly abundant rainfall is composed so largely of clay that irrigation without the most perfect sub-drainage would result in puddling the land, and making it difficult to secure good tillage when the water of irrigation was withdrawn. Yet there are many districts located near the great markets which, on account of the friable nature of the soil and the high price of garden and some other products, lend themselves most admirably to a modified system of irrigation. In many cases the market demand of the large cities would justify sub-irrigation on restricted areas.

Wherever the practice of laying water conduits, from three to eight feet apart and about one foot deep, for sub-irrigation has been adopted, marked beneficial results have followed. In fact, sub-irrigation would seem to be the ideal method of providing moisture for plants, but the cost of preparing and maintaining a sub-irrigating system is so great that it cannot come into general practice. As to the arid and semi-arid districts, it may be said that in most cases the texture and composition of the

soil are admirably adapted to irrigation, and it is largely only a matter of ample water supply, and its cheap transportation to and distribution in the fields, which has to be considered, for in the district where the rainfall is extremely light, or where there is no rainfall at all for three to six months of the year, irrigation can be scientifically practiced: that is, the plants can be supplied with the requisite amount of moisture without any danger of their receiving a great superabundance of it from unexpected rainfall.

As has been said, in all this arid-district the problem must be solved first by the civil engineer. Happily, we have men who are thoroughly competent to undertake this work, and who are interested in the beneficial results which might follow an intelligent system of water storage for irrigating purposes. More than this, if the water can be held back at its sources until needed, floods will be somewhat mitigated, the humidity of the climate increased, and beneficial results will follow in many other ways. It is pleasant to note that the National Government has already provided means to hold back the waters at the sources of the Mississippi, thereby mitigating the floods and making the Upper Mississippi navigable at nearly all seasons of the year.

The following facts are given to show what vast reservoirs may be constructed at small cost when the work is undertaken in an intelligent way by a competent engineer, like Major W. A. Jones. Five dams have already been constructed at a cost slightly

exceeding $600,000.* "In a general way, the reservoirs may be said to be located in the great lake region of the state of Minnesota, in the midst of an extensive area of wooded swamp and open meadows and marshes. Their general elevation is about 1,290 feet above the level of the sea. There are thirty thousand lakes in this lake region, and the state has a water area in its own borders of many thousands of square miles.

"The following tabular statement, compiled from a larger table in the office of the chief of engineers at St. Paul, gives some interesting information as to the immense size of these reservoirs, put in condensed form:

Working height of dam above low water, in feet.		Area of reservoir, sq. miles, high water.	Low water.	Area of water-shed, sq. miles.
Winnibigoshish...	14	161.26	117.	1,442.43
Leech Lake.......	6	233.80	173.19	1,162.80
Pokegama Lake...	9	45.29	24.13	660.23
Pine River	17	33.76	8.	562.07
Sandy Lake.......	7	16.52	33.33	421.50
		490.63	355.65	4,249.03"

Major Jones says: "There is no operation in engineering so fraught with importance to mankind as the regulation of the flow of water which results from rainfall. * * * * * * Given a definite superficial area of land from which all surplus rainfall will flow toward and into one channel, and the benefits which will result to the population along

*W. S. Harwood, Harper's Weekly, No. 2,090, p. 38. (Copyright, 1897, by Harper & Brothers.)

that channel from the control of its water-flow are great and far-reaching. Here are some:

"1. Prevention of floods, or a reduction of their intensity.

"2. A sure supply of water for navigation during the low-water season.

"3. A more nearly uniform distribution of the water for power purposes.

"4. Furnishing water for irrigation purposes.

"5. Preventing deterioration of water used for domestic purposes during low-water periods.

"A desert is a place where rainfall is not sufficient to support life. If the earth's rainfall were uniformly distributed over its surface, there would be no desert. Each desert area is surrounded by a zone where precipitation is sufficient for grass and low bushes, but not for trees or agriculture. This is the border land of desert. The varying effects of climatic changes alternately expand and contract this zone. It may, over an indefinite period of years, contract and absorb the desert—*vide* the Great American Desert—or it may expand and extend its borders far into the region of lands arable without irrigation. There are many indications that over the great plains areas of the northern hemisphere this process is now going on. A careful assemblage of facts will doubtless show that over these great areas and along their wet borders the lakes and streams have for many years past been gradually drying up. And, furthermore, they bear remarkable evidence of a time when the precipitation was far less than at

present. It is, therefore, a matter of gravest importance for the people of the United States to conserve and control precipitation over and near this border land of desert."

There are many districts in the United States which might be treated similarly to the one described above, with all of the beneficial results which have been enumerated. Then, too, there are many badly farmed areas which might better be covered with water than farmed at a loss. Not one reservoir for water storage, but thousands, both large and small, should be constructed. When the science of holding back surplus water economically has been learned and put into practice, and the benefits derived from such practice have been appreciated, it will be an easy task to awaken interest in forestry. Reservoirs alone cannot entirely arrest floods, or furnish as humid an atmosphere as is desired. They must be supplanted by large areas of planted or natural forest belts. To what better use could many of the rocky, steep hillsides and poor farms, which have been made poorer by tillage, be put than to grow trees and to hold back water during periods of abundant precipitation? If one-fourth of the land,—the poorer and rougher areas,—was thrown out of cultivation and allowed, even by nature's slow processes, to cover the nakedness of mother earth and our shame, the climate in time would be changed, present losses, which are now incurred by farming these lands, avoided, while posterity would reap vast and enduring benefits from our thoughtfulness.

DRAINAGE.

Underground drains serve to relieve the land of free water, which is very harmful to most plants if left to stagnate in the earth near the surface. They serve not only to dry the land in early spring, but indirectly to warm it, for if the water is removed the sun's heat warms the soil, instead of cooling it by evaporating the surplus water. If much of the free water in the springtime is carried through the soil by underdrains, then the superabundant water of midsummer will, in like manner, be removed. The rain in the spring is warmer than the soil, and if it percolates through the land to the drains, it parts with its heat and indirectly warms the soil, while the rain in midsummer is cooler than the soil, and in passing down to the drains cools the land.

Underdrains prevent the interstices of the soil from becoming blocked or filled with fine particles of earth held in suspension; that is, they prevent puddling, to some extent. Clayey soils shrink if they become dry, and swell when they are wet. Underdrains tend to prevent the swelling and closing of the pores which have been produced by drying. As soon as air is admitted to the subsoil, the dead roots of plants are decomposed and minute drainage-changels are formed. One of the effects of drainage is to produce many small channels in the soil, which prevent the formation of large cracks that admit the air too freely and thereby cause excessive evaporation. Underdrains promote fertility by opening up the soil

to the oxidizing action of the air, and by making the soil more comfortable for the nitrifying organisms.

The rainfall usually contains ammonia equal to six to eight pounds of nitrogen per acre. The more of the water that comes to the land in rains and snows that can be made to pass through the land in a reasonable time the better, for in passing through, the ammonia is taken up by the soil, the land becomes better aërated and more friable, decomposition of organic matter is hastened, plant-food of all kinds is liberated, and the productive power of the land is increased in many other ways. Well-constructed underdrains assist in mitigating floods, increase the fertility of the soil, cheapen tillage, and prevent or mitigate some of the diseases of plants and the ravages of some noxious insects.

It is evident that if the soil is broken into minute particles by the action of underground drains, its power to hold moisture will be increased. If a drained soil is capable of holding 30 per cent of moisture without giving off free water, it will hold back during wet weather vast quantities of water which would pass off of undrained land, that could hold but 15 per cent of moisture. Fields thoroughly underdrained suffer far less from droughts than undrained fields, other things being equal. Surface drainage, especially of marshes and other wet lands, and the destruction of forests by fire and axe, increase floods to an alarming extent, as they destroy the natural reservoirs and absorbing materials of the land.

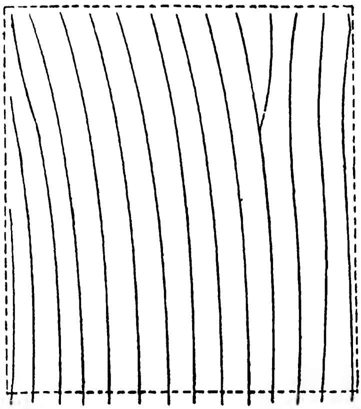

Fig. 27. The proper method of draining a large field.

It is not the purpose to enter into the details of sub-drainage, but the mistake of concentrating water into mains and sub-mains when they might be avoided is so often made, that it seems fitting to discuss one phase of the subject briefly. It is the better plan to let each drain discharge its own water into the open, than to complicate matters by an elaborate system of mains and laterals. Fig. 27 represents a square of forty acres drained by the parallel system, and Fig. 28 a like amount drained by the too common method. If the ditches are placed thirty feet apart in Fig. 27, it would take 58,080 feet of tile to drain the

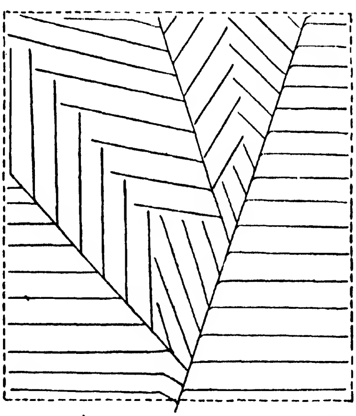

Fig. 28. The common but improper method of draining a large field.

land. It would take the same number of tile to drain the land in Fig. 28, plus 2,640 feet for the mains and sub-mains. These would have to be larger than the tile used in the laterals, and should be placed three or four inches deeper, that the water of the laterals may enter near the top of the mains with a rapid fall. Many connections would have to be made, and nothing would be gained except that fewer outlets would have to be cared for by the second than by the first system. The mains and sub-mains are really not drains, but are expensive conduits for carrying off the water which is brought to the lowest land by the laterals.

CHAPTER VI.

FARM MANURES.

FORMERLY all substances which were spread upon the land for the purpose primarily of enriching it, were designated as manures. Latterly the meaning of the word has changed somewhat, and it does not now embrace commercial fertilizers, nor those substances whose chief object is to improve the physsical condition of the soil. The term is now applied to the excrements of domestic animals, mixed or unmixed with vegetable or other refuse material, and a few other substances; only in rare cases are amendments, or extraneous matters, or fertilizers mixed with them in sufficient quantities to change in any marked way the character of their constituents. The term *excrements* has been substituted for the ancient word *dung*, the meaning of which was somewhat ambiguous. Excrements are the solid and liquid voidings of animals, unmixed with litter. The term *barn manures* has been substituted in some cases for *farmyard manures*, the object being to sharply distinguish those which are cared for and sheltered until they are taken to the field, from those which are left to depreciate in quantity and value by being exposed in the farmyard to the action of the rain and heat,

Farm manures is a generic term, and includes all kinds and classes of refuse matter, whether applied chiefly as an amendment, or for the plant-food contained, or for forming a mulch, or for all three purposes combined. The excrements associated with bedding or other material from different species of animals when thrown together are called *mixed manures*, while those from a single species are designated by the name of the kind of animals which produced them.

GENERAL CONSIDERATIONS RESPECTING THE USE OF MANURES.

Most manures are unbalanced; that is, they contain a relatively high percentage of potential nitrogen and a low percentage of phosphoric acid and potash, provided the comparison is made with the composition of plants grown under common conditions, where mixed agriculture is largely pursued. If the comparison is made with the coniposition of plants alone, then farm manures may be said to be relatively low in potential nitrogen and high in phosphoric acid and potash; but this method of comparison is very misleading, for while the soil is being constantly enriched in nitrogen from leguminous plants which have immediately preceded, from those plants which grow with the crop with which the manures are compared, from potential nitrogen which is being constantly absorbed by moist, friable soils, and from that which is brought to the soil by rain,

the mineral matter is not being augmented from outside sources. It is believed that in the greater part of the arable portion of the United States east of the dry belt, enough nitrogen from the last two sources alone is secured to supply one-third of the wants of the cultivated plants. True, the average yield of farm crops is only one-third of what it might be if superior tillage and underdraining were the rule instead of the exception, and if the effort were abandoned of trying to raise plants on land and in a climate not well adapted to their growth and highest development.

If plants are not well adapted to the soil and climate, they are unable to utilize the food which is present, and tend to languish, although there may be not only a sufficient plant ration, but also a well-balanced one. Consequently, in basing the wants of plants on chemical analyses, and in making comparisons between them and the composition of manures, there is danger of being led into erroneous conclusions. The whole subject is difficult and extremely complex, as plants differ so widely in the power of their roots to make soluble the material in the soil, and also in their power to tolerate an excess of one or more of the elements of growth, or even of substances not necessary to the plant. It is next to impossible to determine by analysis of soil and plant how much and what plant-food should be added to secure best results. Then, too, plants raised for a long time under superior conditions of plant-food, soil and climate, acquire powers not possessed by the

same species grown from time to time under adverse conditions. Not only may plants, like animals, acquire new qualities and increase those already possessed, but they may also, in time, under favorable conditions, become so fixed in their acquired powers that these characters may be transmitted with a good degree of certainty; that is, they become thoroughbred, in the best sense of the word.

Plants vary greatly in their root systems and leaf structure, and hence in their power to secure the necessary elements from the soil and from the atmosphere. Some thrive best with a minimum, others with a maximum amount of moisture; some do best on poor soils, and others will thrive only when there is an abundance of easily available food. To feed plants understandingly is not only extremely difficult, but sometimes impossible; therefore, a most careful study of the wants of plants from the scientific and chemical standpoint may not give the information desired, unless made in connection with close observations of the behavior of the plant throughout its entire period of germination, growth and fructification. Notwithstanding all this, if the investigator begins to question the soil with a knowledge of the composition of the crops to be raised and the manures applied, he is far more likely to obtain true answers to his questions than if he were to trust entirely to science on the one hand, or to visible, external results on the other.*

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*For a sketch of the methods which the farmer may pursue to determine what plant-foods he may use to best advantage, see Caldwell, Bull. 129, Cornell Exp. Sta.

To show more clearly the need of care in drawing conclusions, the following examples are given:

Wheat, with its accompanying straw and chaff, uses, approximately, for every 100 pounds of nitrogen, 33 pounds of phosphoric acid and 63 pounds of potash. Unleached horse manure, if applied in sufficient quantities (supposing that all the plant-food it contains is available) to furnish 100 pounds of nitrogen, would, at the same time, furnish 58 pounds of phosphoric acid and 139 pounds of potash; or an excess above the requirements of the plant of 25 pounds of phosphoric acid and 76 pounds of potash. When the problem is reduced to practice, it is found that notwithstanding there seems to be an excess of phosphoric acid and potash as compared with nitrogen, the wheat may still be unable to form straw firm enough to resist rust or stiff enough to carry it safely to the harvest period. Or in other words, while the comparison from the chemical standpoint shows that there is an excess of phosphoric acid and potash in the horse manure, as compared with the composition of wheat, the plant shows by its soft texture, tendency to rust and inability to stand up and fruit bountifully, that it is gorged with nitrogen. This would seem to show that ordinary soils under rotation receive large amounts of nitrogen from sources outside of the manures, often quite as large as plants which are sensitive to nitrogen (as oats, for example) can use, and still remain strong and healthy.

If the average composition of manure, as found in a large number of experiments made at the

Cornell University Station with 125 animals (cows, calves, pigs, horses and sheep), is compared with the composition of Indian corn, allowing that the stalk is to the grain as three to one, and with some other leading crops, the following results are reached:

	Phos. acid.	Potash.
Mixed manure contains, for every 100 lbs. nitrogen	49.6 lbs.	77.8 lbs.
Maize (whole plant) contains, for every 100 lbs. nitrogen	32. "	100. "
Oats, 1½ straw to 1 grain, contain, for every 100 lbs nitrogen	37.3 "	82.6 "
Barley, 1½ straw to 1 grain, contains, for every 100 lbs. nitrogen	31.5 "	98.7 "
Mangolds, ⅛ tops to 1 roots, contain, for every 100 lbs. nitrogen	45. "	180. "
Potatoes, ¼ tops to 1 tubers, contain, for every 100 lbs. nitrogen	27. "	110. "

The above shows that for every 100 pounds of nitrogen which the manure furnishes, there is an excess of 17.6 pounds of phosphoric acid and a deficiency of 22.2 pounds of potash, when compared with the composition of maize. All of the plants mentioned require a less proportion of phosphoric acid than would be furnished by the manure, and without any exception they all require a greater proportion of potash, as compared with the nitrogen, than the manure would supply.

Most good farms are kept in a productive condition by the aid of rotation and manures, with an occasional light application of commercial fertilizers to the cereals. The table above would seem to indicate that both nitrogen and potash should be applied

in excess of the phosphoric acid; yet, in practice, fertilizers containing a relatively high percentage of phosphoric acid and a low percentage of nitrogen, as compared with the composition of the cereals, are almost invariably used. In fact, in many cases, as in the growing of barley and wheat, the best financial results are often reached by the application of phosphoric acid alone. No facts are at hand to show whether, in manures, a greater percentage of one of these elements over the other two is available. We know only that a part of the nitrogen furnished by the manure may escape by leaching, but it is very possible that, on account of chemical changes or bad tillage, the phosphoric acid which the manure contains is not as available as the potash or the nitrogen. It is certain that when land is treated to superior surface tillage, especially during the warmer months, large amounts of nitrogen are set free,—so large, in fact, that in some cases the plants are injured by the excess. This would seem to indicate that much of the potential nitrogen in the soil is always in such forms, under ordinary tillage, as to be useless to the plant, and that extra tillage may give more economical results than the application of nitrogenous fertilizers would.

All of the discussion so far is applicable to most of those localities where grasses, clover and the cereals are raised in shorter or longer rotation, but as soon as the dry districts, or a warm climate and more sandy soil are reached, the conditions are so changed that radically different practices of tillage

and manuring should be followed. In the cotton belt, which extends over a wide area and embraces a variety of soils, climates and elevations, no methods of manuring can be uniformly recommended. On the lighter lands kept constantly under the plow, nitrogen is lamentably deficient. Farm manures in that section are never to be had in large quantities, and are often entirely wanting. A dressing of cotton-seed meal, which contains between 5 and 7 per cent of nitrogen, usually produces good results. In all the southern country a much larger use should be made of cover crops and leguminous plants, such as the cow pea, for a four-fold benefit to the soil would be secured,—added humus, an increase in nitrogenous compounds, liberation of mineral matter through the action of plant roots, and the bringing from the subsoil to the surface soil of plant-food which is now beyond the reach of the roots of some of the ordinary crops, such as the cereals.

On the fertile prairies west of the 99th meridian, the problem is not one of plant-food, but how to furnish moisture, and, consequently, a discussion of fertility as applied to one-third of the United States is superfluous until some means has been found for securing and utilizing the vast stores of plant-foods already in the soil, most of which are made easily available whenever and wherever the plants are supplied with moisture,—that universal vehicle for carrying animal and vegetable nutrition both into and out of circulation.

From what has been said it will be possible to

draw some general conclusions respecting the manuring of the land:

(1) That while farm manures are almost always valuable in improving the physical condition of the land and augmenting its power to hold moisture, and in helping in various ways to make available the dormant energy already in the soil, yet they contribute only one factor—sometimes a very small one—in determining the quality, quantity and value of a crop. Their true value depends not only on the composition but quite as much on the ability of the husbandman to associate other factors with them, which, taken together, lead to the highest success.

(2) That while most soils contain a surplus of plant-food over and above the wants of the crop in any one season, yet the question of highest economic results as between tillage and added plant-food can be determined only by experiment.

(3) That increased tillage, and the application of farm manures and other forms of plant-food, may largely fail of their object if the plants grown are not suitable to the climate, or have not the inbred power to make the best use of their improved environment.

(4) That the knowledge of the composition of the plant sometimes gives no indication of what plant-food should be added to the land to secure the most satisfactory results; for example, clover contains a high percentage of potential nitrogen, yet thrives well on land deficient in it.

(5) That an ordinary analysis of soil gives little

indication as to the availability of the elements which it contains.

(6) That having mastered the sciences which underlie agriculture, and having learned how to apply them to the growth of one or more kinds of plants in any particular locality, and how best to make soil fertility available, and how to select plants and apply fertilizers and manures, still all this knowledge may be of little economic value if the one great factor of moisture is lost sight of.

(7) That it is far easier to start with only a few known facts, even without a knowledge of how best to use them, in the endeavor to determine the best practice, than to ignore these fundamental facts and to endeavor to discover everything by experiment.

(8) That in no case should the fact that many soils contain vast stores of plant-food lead to waste or carelessness in the management of the manurial products of the farm, for, except on lands which are recuperated by overflow or irrigation, natural or artificial, the time is never far distant when even the richest land will fail to give maximum results, if unassisted.

(9) That all home resources of fertility should be fully utilized before resort is had to purchased plant-food.

(10) That timeliness, adaptation, thoroughness, economy in the use of energy, and good judgment in the management of details—that is, farm-practice—play such important parts in modern agricul-

ture that they may be considered to be equal, if not superior, to the facts revealed by chemistry, botany, and allied sciences. Knowledge and the application of it should not be divorced, but joined so firmly by intelligent thought and action that the twain become one.

FACTORS WHICH DETERMINE THE QUALITY OF FARM MANURES.

Manures vary greatly in their chemical composition and also in their beneficial effects. These variations are due to many causes.

Young animals digest their food more closely than old ones do. Very young mammals are usually fed on milk, all of which is believed to be digestible, while the constituents of the food of mature animals are never wholly digested or assimilated. Then, too, in the young, growing animal, all of the constituents of its food are wanted for growth and development, while the mature one has its structure fully completed, and requires food only for maintenance and for surplus product, as increase in weight or production of milk. As the digestive and assimilative powers are more active in young than in old animals, the excrements of the former contain less of the manurial elements found in the food consumed than those of the latter. Young animals change vegetable into animal products more economically than old ones, and hence they are likely to give more pounds increase in weight for a given number of units of

food, but the resulting excrements are less valuable than those from mature animals are.

Species of animals vary as plants do in their power to live on coarse, unconcentrated or tough food, and it is believed that they vary in their powers of digestion and assimilation, though no extended and exact experiments have been made in this direction. The question is frequently asked, if sheep make a better use of their food than cattle or horses; that is, if a ton of hay and a ton of corn be fed to sheep, and the same amounts to cattle and horses, all mature and under conditions as nearly similar as possible, which species will assimilate the greatest percentage of its food, and which will give the greatest manurial value in its excrements? The hay and maize being the same in quantity and quality, in either case the amount of fertilizing elements in the solid excrements would determine the relative powers of the species to assimilate food.

The uses to which animals are put frequently modify in a marked degree the value of their excrements. Those which reproduce and rear young make poorer excrements than do those of like species under similar conditions which are not bearing young. Animals giving milk produce poorer excrements than those which are not in milk, when placed under like conditions. In other words, animals which are put to laborious work for many hours per day require a wide (or carbonaceous) ration, if they are to be well sustained in energy, and prevented from using expensive nitrogenous compounds in its production;

while animals kept for speed, and those which are required to do very severe work for only short periods, are most satisfactorily sustained on a narrower (or nitrogenous) ration.

Mature animals which are non-productive and are not increasing in weight return sooner or later nearly all of the manurial constituents of their food in their excrements (manifestly all cannot be returned, as dead particles of skin and hair are thrown off), while only one-half to two-thirds is returned by young and rapidly growing ones. Cows in full milk return in their excrements only about 65 to 75 per cent, while fattening animals return 85 to 90 per cent of the fertilizing elements of their food.

The unscientific reader may not fully understand how animals can live, increase in weight and grow fat, and yet return to the manure pile nearly all of the valuable fertilizing constituents which their food contained. Given a suitable ration, the animal first of all uses the carbonaceous or heat-producing materials for maintaining normal temperature, and if not enough is available it uses nitrogenous compounds, and lacking in this, it draws on the stored fat in the system. Substituting the fats of the animal, or nitrogenous compounds, for the less expensive carbonaceous heat-producers of cattle foods, is usually poor economy. After the animal heat is supplied, the balance of carbonaceous matter may be transformed into energy required for the activities of life and work. The surplus may be transformed into products of commercial value. The proteids may

also give commercial products, or be stored in the system, and finally pass off in excrement.

While vegetable carbonaceous matter is decomposing or slowly oxidizing, it may improve the physical condition of the soil, and act beneficially in other ways. About one-half of the dry weight of plants is carbon. Carbonaceous matter may be used to improve the soil, but plants grow in earth in which it is entirely wanting. Therefore, the carbonaceous matter in foods may be used by the animal for the production of heat and energy, or transformed into salable carbonaceous products, without reducing the fertilizing value of the excrements. The albuminoids, or proteids, *i. e.*, potential nitrogen, are used by the animal for building and nourishing the flesh, tendons and the like, and when they have been in the system for a time and have become old, they are thrown off, chiefly through the urinary organs, in somewhat changed forms, and are replaced by fresh albuminoids taken from the food ; so that if the animals are not gaining in weight or not making a surplus product, they not only return in their voidings nearly all of the nitrogenous compounds, but also the phosphoric acid and potash which their rations contained. It will be seen what a prominent part domestic animals may be made to play in maintaining the fertility of the land.

Heat and muscular power are forms of force or energy. The energy is developed as the food is consumed in the body. The unit commonly used in this measurement is the calory, the amount of heat which

would raise the temperature of a pound of water 4° F. The following general estimate has been made for the average amount of potential energy in one pound of each of the classes of nutriments:*

	Calories.
In 1 pound of protein	1,860
In 1 pound of fats	4,220
In 1 pound of carbohydrates	1,860

It is estimated that one unit of digestible fat is equal to a little over two units of albuminoids (proteids) for the production of heat. A narrow ration is usually more expensive than a wide one, as digestible proteids cost twice per unit more than carbohydrates, while the former does not produce heat as satisfactorily as the latter.

In some parts of the United States, cattle foods containing an unusually high percentage of albuminoids are frequently used in excess, because of their low price and the high value of the excrements of the animals which consume them. An extremely narrow ration may sometimes be economical, but it is always dangerous, as it tends to overload the kidneys and disturb the normal action of the urinary organs.

The kinds of food consumed modify the composition and value of the resulting excrements. If a ration containing a sufficient supply of carbohydrates ("heat-producers") and a superabundance of proteids ("flesh-producers") is fed, the excrements will be more valuable and contain a larger relative percent-

*Yearbook of the Department of Agriculture, 1894, p. 547. Appendix by W. O. Atwater.

age of potential nitrogen than they would if the ration contained only a sufficiency of flesh-formers and a superabundance of heat-producers. Animals which are giving milk produce poorer excrements when fed easily digested rations than when fed those which are less digestible. Animals liberally fed produce richer excrements than those which are underfed.

The individuality of the animal may modify the character of the excrements in a marked degree, as some animals possess greater powers to transform their food into surplus products than others. The greater this power, the more valuable the animal and the less valuable the excrement.

The amount of water consumed also modifies the value of the manure per ton. Rations which contain a relatively high percentage of albuminoids call for larger consumption of water than wide or carbonaceous ones do. Hence a liberal supply of albuminoids tends to make the solid excrements watery, and while an excessive consumption of water may increase the total weight of excrements, it diminishes the percentage of their valuable constituents.

The quantity of bedding used affects the quality of the manures. If the bedding is poorer than the excrement, as is usually the case, the more bedding used the lower will be the percentage of manurial value. The bedding may not only promote the comfort of the animal, but it may also conserve excrements, and therefore manures containing a moderate amount of straw or other absorbents may be as rich in the end as those containing a small amount or

none, for in the latter case the excrements may lose some of their valuable constituents for want of being mixed with absorbents.

Manure is also affected by the kind of bedding used. Pine straw is believed to seriously injure it, while pine shavings and sawdust, when used in moderate quantities and applied in the right way, are believed not to be injurious; but if used liberally, and the manure is placed on light soils in large quantities and plowed under, serious damage may be produced during droughts. No careful and long-continued experiments have yet been made to determine the extent or the real cause of this injury, but observation leads to the conclusion that the excrements of animals mixed with shavings are not so available to plants as when mixed with straw. It would naturally be inferred that the turpentine and other antiseptic compounds found in some kinds of sawdust and shavings, and especially in pine straw, would seriously arrest decomposition, which action may be undesirable. Decomposition, if kept within proper limits, is desirable, for the more thoroughly the organic material of manures is broken down the more available their constituents become. Manures containing large amounts of sawdust and shavings, if kept moist, and prevented from heating until they are thoroughly broken down, lose all of their deleterious characteristics. Manures containing liberal quantities of dry bedding (which decomposes slowly) serve their best purpose when spread evenly over grass lands in the fall. Thus distributed, they act as

a mulch, fertilizer, conserver of moisture, and give protection to the roots of plants.

Even mixed manures, composed partly of straw bedding, may do injury, especially in a dry time, if applied in liberal quantities and plowed under, since they break the capillary connection between the surface soil and subsoil, thus causing the surface soil to become drier than it would had the coarse manures not prevented the moisture from passing upwards toward the surface. King,* in three years' experiment with barn manures, found "That for manured fallow ground the surface foot contained 18.75 tons more water per acre than adjacent and similar but unmanured land did, while the second foot contained 9.28 tons and the third 6.38 tons more water, making a total difference in favor of the manured ground amounting to 34.41 tons per acre. The largest observed difference was 72.04 tons in the dry season of 1891. Early in the spring, on ground manured the year before and fallow, there was an observed difference amounting to 31.58 tons per acre. * * * * * Wetting the surface of sand with water leached from manure reduced the rate of evaporation from the surface from 64.98 pounds per unit area to 32.72 pounds in the same time, under otherwise identical conditions."

*"The Soil," pp. 289-290.

CHAPTER VII.

MANURES PRODUCED BY VARIOUS ANIMALS.

The amounts and values of the excrements, mixed or unmixed with bedding, which are produced by different classes of farm animals in given lengths of time when fed on varied amounts and kinds of food, have been determined so often and with such painstaking accuracy that full reliance can be placed on the results. While it is true that the three elements of chief value in manures and animal excrements,—nitrogen, phosphoric acid and potash,—are not so available as they are in skilfully manufactured commercial fertilizers, yet they are usually computed at commercial prices, for there should be some convenient and uniform standard upon which to base comparisons and with which to make calculations. On the other hand, manures furnish available humus, and a mulch if they are spread upon the surface, and they also tend to increase the water-holding power of the soil, and to improve its texture or physical condition. In many cases it is believed that these benefits are a full equivalent for the less soluble character of the fertilizing constituents of manures as compared with commercial fertilizers. When the soil has a reasonable amount of easily available plant-

food, it is probable that such may be the case, but the ultimate welfare of plants depends so much on a healthy, vigorous start and abundant root development, that the more quickly-acting commercial fertilizers may be more valuable than the slower-acting farm manures, whenever the land is deficient in readily available plant-food. Careful observations and experiments only can determine the relative values of the constituents found in fertilizers and manures. The final productive value, as evidenced in the harvest, depends so much on the skill of the farmer, on climate, character of the plant, and rainfall, that it can never be certainly predicted whether profit or loss will result in the purchase and application of nitrogen, potash and phosphoric acid in any form. One thing is certain, that the careful husbanding of farm manures, and the application of them in reasonable quantities in almost any form, result in improved fertility and increased profits in the final outcome.

In the computations of the value of manures and fertilizers, the question must constantly arise in the mind of the reader, "If phosphoric acid and potash are worth 7 and 4.5 cents per pound respectively, is the nitrogen worth 15 cents per pound?" If it is secured in the usual commercial form, it cannot be purchased for much less. If the land is deficient in mineral plant-food, such cannot be augmented without transporting it to the field in some form or other. True, it can be made more available by tillage and other means. With nitrogen, however, it is different,

for positive additions can be made to the soil by the use of leguminous plants; and this, too, with little added cost, as clover and similar plants furnish forage of value equal to the cost of their production, while the nitrogen in the roots and stubble augments the store of it which was in the soil before the clover was grown. Nitrogen can be secured quickly and cheaply by purchasing and feeding food containing a high percentage of albuminoids. Then, too, there may be a profit in feeding the animals, and if so, the value of the manures produced is an additional profit; or it may be considered that the manures are secured at no cost but the hauling and distributing.

The foregoing discussion leads to the conclusion that under some circumstances, nitrogen is not worth to the farmer its cost price of 15 cents per pound, and that it is usually better for the farmer to secure it through leguminous plants and manures from animals fed a fairly narrow ration, than to pay even 10 cents per pound for it in commercial forms; so it is the opinion of the author that all of the tables of values given in the foregoing and succeeding chapters should be amended to correspond with local conditions and needs.

Tables are published which give estimated trade values for fertilizers, but they are no more accurate, when reduced to actual value as secured by the farmer, than estimated values for farm manures are.

In some towns stable manure is given away, in others it may be sold for a dollar a load. In the production of some special crops, the gardener may

be willing to pay even more than 15 cents per pound for nitrogen, if he is not able to get it for less, rather than to do without it.

A DISCUSSION OF THE MANURE OF CATTLE.

At the Cornell Experiment Station* the manure produced in twenty-four hours by eighteen Jersey and Holstein grade cows in full milk was weighed and analyzed. The following tables set forth the detailed results,† and also the amounts and kinds of food used. The regular winter rations for a day were fed, as follows:

Mixed hay	114 lbs.
Maize ensilage	893 "
Mangolds	186 "
Mixed food	154 "

The mixed food was composed of 12 parts of wheat bran, 9 parts cotton-seed meal, 3 parts maize meal and 1 part malt sprouts, by weight, fed twice a day.

TABLE XI.

Results of the feeding.

Weight of 18 cows, 20,380 lbs.	18 cows for 1 day.	Average per cow per day.
Food consumed	1,347. lbs.	75. lbs.
Water drunk	876. "	49. "
Total excretion	1,452.5 "	81. "
Nitrogen	7.35 "	.41 "
Phosphoric acid	5.01 "	.28 "
Potash	7.40 "	.41 "

*Bull. 27, Cornell Exp. Sta., May, 1891.

†Nitrogen is here and elsewhere computed, unless otherwise specified, at 15 cents, phosphoric acid at 7 cents, and potash at 4½ cents per pound.

TABLE XI.—CONTINUED.

Weight of 18 cows, 20,380 lbs.	18 cows for 1 day.	Average per cow per day.
Value of nitrogen	$1.10	$0.06
Value of phosphoric acid	.35	.02
Value of potash	.33	.02
	$1.78	$0.10

TABLE XII.

Percentage composition of the excrement.

	Per cent.
Nitrogen	.51
Phosphoric acid	.35
Potash	.51

Computed value per ton, $2.46.

A few days after the above investigation, a second one was made with four cows for twenty-four hours, in full milk, under similar conditions:

TABLE XIII.

Feeding and manure—Gross figures.

	Lbs.
Food per cow, per day	76
Water " "	40
Excrements per cow, per day	82
Total solid excrements, for four cows	255
Total liquid " " " "	72.25

Composition.

	Solids, %	Liquids, %	Mixed, %
Nitrogen.........................	.26	1.32	.49
Phosphoric acid..................	.28		.22
Potash...........................	.20	1.	.38

Value per ton, $2.08.

The amounts of the fertilizing materials are set forth in the following table:

TABLE XIV.

Experiment with four cows, one day.

	Solid lbs.	Solid value.	Liquid lbs.	Liquid value.	Both lbs.	Both value.	Daily av. val. per cow.
Nitrogen.........	.65	$0.10	.95	$0.14	1.60	$0.24	$0.06
Phosphoric acid..	.71	.05*			.71	.05	.01+
Potash...........	.50	.02	.72	.03	1.22	.05	.01+
	1.86	.17	1.67	.17	3.53	.34	.085

Investigations in 1883 and 1884† with three cows three days gave the following results (the average weight of the cows being 1,192 lbs.):

TABLE XV.

Gross figures of experiment with three cows three days.

	lbs.
Clover hay consumed	122
Cut maize stalks consumed	41
Cotton-seed meal "	45
Malt sprouts consumed	42
Maize meal "	42
Milk produced	285
Manure, including 45 lbs. cut maize stalk bedding	802

The food contained nitrogen, phosphoric acid and potash estimated at $1.60. The manure was not analyzed, but, allowing that it contained 60 per cent of the fertilizing material in the rations, the estimated value would be, for the three days, $0.96 or $0.10⅔ per cow per day.

The entire product of manure at Cornell in 1883–4 was kept in a covered barnyard. The accumulated mixed and trampled manure of cattle and

* There was only a trace of phosphoric acid in the urine.

†Third Report Cornell Exp. Sta., 1885.

horses was about two feet thick. A large number of samples were taken at various depths, chopped fine, mixed and analyzed, with the following results:

TABLE XVI.

Manure from a covered yard.

	Per cent.		
Moisture	72.95		
Nitrogen	.78	at	$0.15
Phosphoric acid	.40	at	.07
Potash	.84	at	.0425

Value per ton, $3.61.

During the winter, 311 double-box wagon loads were produced. Every tenth load was weighed. The loads averaged, in round numbers, 3,000 pounds each. The winter's output of manure, therefore, was about 466 tons. These results were so astonishing, and the data so imperfect, that the following year the number and kinds of animals, the time embraced in the investigation, and the weight of the manure, were all carefully noted.

From October 1, 1884 to March 2, 1885, 199.25 tons of manure were produced at Cornell by a herd of 12 spring calves, 7 winter calves, 1 bull, 24 cows, 12 horses and 1 colt, 57 animals in all. Allowing that the 20 young animals were equal to 10 adults, there would be the equivalent of 47 full grown animals. Each load of manure was weighed, sampled and prepared for the chemist, as described above. The numerical results are as follows:

TABLE XVII.

Composition and computed values of samples.

Moisture	75.57 per cent.
Nitrogen	.68 " "
Phosphoric acid	.29 " "
Potash	.70 " "
Nitrogen at 15 cents	$2.04 per ton.
Phosphoric acid at 7 cents	.41 " "
Potash at 4¼ cents	.60 " "
	$3.05
For the 150 days	$607.71
Per cow per day	.0862

The following table from Morton's Cyclopœdia of Agriculture, Volume II., gives the average production of manure in several experiments, but the average weight and age of the animals are not given, and in some cases the food of the animals was succulent, in others air dried:

TABLE XVIII.

Comparative amounts of excrements.

	Solids.	Liquids.
A horse, annual	12,000 lbs.	3,000 lbs.
A cow, annual	20,000 "	8,000 "
A sheep, annual	760 "	380 "
A pig, annual	1,800 "	1,200 "

In order to present a more detailed view of the quantity, composition and estimated value of farm manures which are made under various conditions and in divers places, the following figures are transcribed from various sources:

TABLE XIX.

Manure from cattle fed exclusively upon the waste from a cotton-seed oil mill.

(Bull. No. 1, Vol. II., Tennessee Exp. Sta.)

	Per cent.		Per ton.
Moisture	77.50		
Nitrogen	.53	at 15 cents,	$1.59
Phosphoric acid	.22	" 7 "	.31
Potash	.36	" 4.5 "	.32
			$2.22

TABLE XX.

A 4-year-old Jersey in milk, for nine days produced 14.89 lbs. of milk and the following amounts of excrements per day.

(Annual report for 1891, N. Y. Exp. Sta.)

Solids	49.5 lbs.
Liquids	21. "
Total per day	70.5 "

TABLE XXI.

Value of manure from six cows.

(Same as above.)

Average weight of animals	929.8 lbs.
" " " solid excrement	42. "

Value per ton of solid excrements of each animal.

Jem and Meg	$1.31
" " " 2d trial	1.38
Nellie	1.84
Spot	1.35
Broad	2.64
Whitey	2.11
Average	**$1.77**

TABLE XXI.—CONTINUED.

Urine per day.

Jem	15.9 lbs.
Meg	15.4 "
Flora	21. "
Spot	8.9 "
Star	6.9 "
Broad	17.9 "
Nellie	20.5 "
Average	15.2 "

No analysis of the urine is given, but it is stated to have been even more valuable than the solids.

TABLE XXII.

Mixed manure, young cattle and a few horses.

(Report for 1889, Conn. Exp. Sta.)

	Per cent.		Per ton
Moisture	77.08		
Nitrogen	.53	at 15 cents,	$1.59
Phosphoric acid	.34	" 7 "	.48
Potash	.71	" 4.5 "	.64
			$2.71

TABLE XXIII.

Mature cows liberally fed, producing a fair amount of milk all stages of gestation.

(Same as above.)

	Per cent.	Lbs. per ton.		
Moisture	71.69			
Nitrogen	.43	8.6	at 15 cents,	$1.29
Phosphoric acid	.3	6.	" 7 "	.42
Potash	.48	9.6	" 4.5 "	.43
				$2.14

TABLE XXIV.

Old yard manure from young cattle fed hay in yard. Well rotted, washed manure, weight and bulk reduced by exposure.

(Same as above.)

	Per cent.	Lbs. per ton.			
Moisture	54.7				
Nitrogen	.46	9.2 at	15	cents,	$1.38
Phosphoric acid	.72	14.4 "	7	"	1.00
Potash	.16	3.2 "	4.5	"	.14
					$2.52

TABLE XXV.

Amount of milk and of solid and liquid excrements produced by a herd of 12 cows for one year, computed by weighing the amounts of solids and liquids for one day in each month.

(Agr. College, Denmark, 1889-92, Tiddskr. Landökon. 12, 1893.)

	Lbs. per cow per year.
Milk	7,519
Solid excrements	18,432
Urine	6,454

Composition of urine.

	Per cent.				Per ton.
Nitrogen	1.187 at	15	cents,		$3.56
Phosphoric acid	.021 "	7	"		.03
Potash	1.272 "	4.5	"		1.14
					$4.73
Per cow per year					15.26
Urine of entire herd per year					$183.12

TABLE XXVI.

Manure from milch cows.

(Report for 1890, Conn. Exp. Sta.)

	Per cent.	Lbs. per ton.			
Moisture	82.42				
Nitrogen	.42	8.4 at	15	cents,	$1.26
Phosphoric acid	.204	4.08 "	7	"	.29
Potash	.3	6. "	4.5	"	.27
					$1.82

This manure (Table XXVI.) was kept closely packed in a manure house having a cement floor.

TABLE XXVII.

Fresh cow manure.

(S. W. Johnson.)

	Per cent.	Lbs. per ton.	
Moisture	85.3		
Nitrogen	.38	7.6 at 15 cents,	$1.14
Phosphoric acid	.16	3.2 " 7 "	.22
Potash	.36	7.2 " 4.5 "	.32
			$1.68

TABLE XXVIII.

Cow manure from center of dung heap.

(Germany, Schmid.)

	Per cent.	Lbs. per ton.	
Moisture	77.71		
Nitrogen	.54	10.8 at 15 cents,	$1.62
Phosphoric acid	.13	2.6 " 7 "	.18
Potash	.46	9.2 " 4.5 "	.41
			$2.21

TABLE XXIX.

From cows fed 100 lbs. green clover, 5 lbs. rye straw per day.

(R. H. Hoffman.)

	Per cent.	Lbs. per ton.	
Moisture	72.87		
Nitrogen	.79	15.8 at 15 cents,	$2.37
Phosphoric acid	.20	4. " 7 "	.28
Potash	1.69	33.8 " 4.5 "	1.52
			$4.17

TABLE XXX.

Fresh cow manure with litter.

(Wolff.)

	Per cent.	Lbs. per ton.
Moisture....................	77.5	
Nitrogen....................	.34	6.8 at 15 cents, $1.02
Phosphoric acid.............	.16	3.2 " 7 " .22
Potash......................	.40	8. " 4.5 " .36
		$1.60

TABLE XXXI.

Summary of the computed values of the cattle manures.

	Per ton.
Cornell University Experiment Station................	$2.46
" " " "	2.08
" " " "	3.61
Tennessee Experiment Station	2.22
Connecticut " "	2.71
" " "	2.14
" " " (rotted)..............	2.52
" " "	1.82
S. W. Johnson....................................	1.68
Schmid (Germany).................................	2.21
R. H. Hoffman	4.17
Wolff..	1.60
Agriculture College, Denmark (urine)	4.73
New York, Geneva (solids)	1.77
Average per ton..................................	$2.43

A few of the samples were slightly mixed with manure from other animals.

TABLE XXXII.

Cow manure, various kinds of feeding.

(Dr. Thompson, Morton's Encyclopedia of Agriculture.)

	Excrements.
Cows fed 100 lbs. grass, produced per day	71 lbs.
" " 80 " " 4¾ barley, produced per day.........	78 "
" " 25 " hay, 10½ crushed malt, produced per day...	77 "
" " 168 " turnips, 11 straw, produced per day.........	135¾ "

TABLE XXXIII.

Manure from calves.

(Bull. 56, Cornell Exp. Sta.)

	Exp. No. 1	No. 2
Length of experiments in days	12.	15.
Weight of two calves in pounds	379.	580.
Pounds of nitrogen consumed	5.042	3.064
" " phosphoric acid consumed	1.939	1.308
" " potash consumed	1.519	1.871
Pounds of nitrogen recovered	1.983	2.22
" " phosphoric acid recovered	.314	.820
" " potash recovered	1.556	1.642
Manure per ton	$1.69	$2.67
Excrement per ton	$1.60	$2.79

Lot 1 was fed largely on skimmed milk, receiving 707 pounds during the experiment. Lot 2 had no skimmed milk, its food consisting of maize and linseed meal, bran and hay. The potash consumed in experiment No. 1 is slightly less than the amount recovered. This discrepancy is no larger than might be expected from the fact that no two samples can ever be exactly the same. It will be noticed that in experiment No. 2, nearly all of the potash consumed was recovered in the excrements. It is evident that while these young animals utilized a large proportion of the nitrogen and a fairly liberal proportion of the phosphoric acid, they stored up only a small portion, if any, of the potash.

STUDIES OF HORSE MANURE.

The value of manure from horses, like that from other species of animals, is modified by age, food,

and kind and amount of bedding. While the excrements contain less moisture than those produced by cows, the liberal amount of bedding used in the horse stable usually reduces the value of the manure per ton to that produced by the cows.

Nine horses produced in one day, when not at work, bedded with 38½ lbs. straw, as follows (Bull. 13, Cornell Exp. Sta. 1889):

Weight of manure	529.5 lbs.
" " excrements	491. "
Average excreted per horse per day	54.5 "

TABLE XXXIV.

Composition of manure of above horses.

	Per cent.		Per ton.
Water	70.79		
Nitrogen	.51	at 15 cents,	$1.53
Phosphoric acid	.21	" 7 "	.29
Potash	.53	" 4.5 "	.48
			$2.30
Per horse per day			.062

TABLE XXXV.

Gross figures from eight horses one day, when not at work.

(Bull. 13, Cornell Exp. Sta.)

	Lbs.
Total weight, manure and bedding	496.
Weight of bedding	30.
Total weight of excrements, solid and liquid	466.
Average excreted per horse per day	58.25
Per ton of manure	$2.30
Per horse per day	.075

TABLE XXXVI.

Manure from all the horses in the stables for 7 days.

(Bull. 27, Cornell Exp. Sta.)

Excrement	3,319 lbs.
Straw bedding	681 "
	4,000 "

	Per cent.		Per ton.
Water	72.		
Nitrogen	.49	at 15 cents,	$1.47
Phosphoric acid	.37	" 7 "	.52
Potash	.90	" 4.5 "	.81
			$2.80

TABLE XXXVII.

Giving the composition of the straw used for bedding. Owing to the small amount of water content as compared with the manure, it shows a relatively high value. Wheat straw used for bedding, sampled in April.

	Per cent.		Per ton.
Water	6.70		
Nitrogen	.61	at 15 cents,	$1.83
Phosphoric acid	.28	" 7 "	.39
Potash	.70	" 4.5 "	.63
			$2.85

TABLE XXXVIII.

Excrements from 10 draft horses at work for 11 days, two of which were Sundays. On the other days they were out of the stable an average of about eight hours. Total excrements, 3,461 lbs.

(Cornell.)

	Per cent.		Per ton.
Nitrogen	.47	at 15 cents,	$1.41
Phosphoric acid	.39	" 7 "	.55
Potash	.94	" 4.5 "	.84
			$2.80
Average per horse per day			.043

Computing the loss of excrements while the horses were at work from the results given in the following tables, it is found that three-fifths of the excrements were saved. If all had been saved, the result would have been a little more than 7 cents per day per horse.

TABLE XXXIX.

Amount and content of manure from four work horses and one 2-year-old colt in 24 hours.

(Bull. 56, Cornell Exp. Sta., 1893.)

Total weight of horses	6,410	lbs.
Land plaster used	129	"
Straw bedding	112.75	"
Total weight of manure	555	"

Composition of manure.

	Per cent.		Per ton.
Water	48.69		
Nitrogen	.49	at 15 cents,	$1.47
Phosphoric acid	.26	" 7 "	.36
Potash	.48	" 4.5 "	.43
Manure			$2.26
Excrements			3.20
Excrements per year per 1,000 lbs., live weight			$27.74
" " day " " " " "			.076
Excrements recovered per 1,000 lbs. per day			48.8 lbs.

TABLE XL.

Summary of computed values of horse manure.

(Cornell Exp. Sta.)

	Per ton.
9 horses	$2.30
8 "	2.30
All horses in stable	2.80
10 draft horses	2.80
4 horses and one colt	2.26
Excrements	3.20
Straw bedding, Table xxxvii	2.85
Average of all manure	2.49

This shows that the computed value of the excrements is nearly one-half of the cost of the food. Experience leads to the conclusion that this value can seldom or never be realized from the manures when applied to the land; but there is no other way of making comparisons between various kinds of manures and fertilizers without using a uniform standard for comparison. As has been explained, the real values of both manures and fertilizers to the farmer are dependent upon so many conditions that the true recoverable value can never be known in advance. It would, perhaps, be safe to value barn manures at fully one-half of their computed values, as shown by the tables.

LIVERY STABLE MANURE.

Livery stables in villages in the grain-growing districts often arrange with the farmer for fresh straw bedding without charge, the resulting manure to belong to the farmer who furnishes the straw. From investigations made at the Cornell Experiment Station, and from facts furnished by Director H. P. Armsby, State College, Pa., the following conclusions may be drawn:

That a ton of straw as it comes from a thresher, and as used in village livery stables, will result in five tons of manure, if drawn as soon as made.

That fresh horse manure computed as above is worth $2.45 per ton.

That a ton of straw, computed as before, is

worth for manurial purposes $2.75 per ton. We then have data for the following figures:

Five tons of manure at $2.45	$12.25
Less one ton of straw at $2.75	2.75
	$9.50

There appears to be a value of $9.50 to compensate for drawing one ton of straw to the village and five of manure back to the farm; but if the manure is thrown out of the stable under the eaves and left for any considerable time, one-third to one-half of its value will probably be lost. Then, too, it should be remembered that the fertilizing constituents in the manure are computed at liberal prices.

DISCUSSION OF SHEEP EXCREMENTS.

Two sheep were fed in each of six experiments, each animal standing on a galvanized iron pan (Bull. 56, Cornell Exp. Sta., 1893). In order to show the effect of foods on the composition of manure, the following tables are given:

TABLE XLI.

Food consumed.

No. of exp.	Water.	Lbs. hay.	Lbs. maize.	Lbs. oats.	Lbs. wheat bran.	Lbs. Cot.-seed meal.	Lbs. linseed meal.
1	185.75	81.25	11.5	11.5			
2	144.25	58.5	11.25	11.25			
3	188.	50.	40.55	41.25			
4	298.	92.5			35.29	17.64	8.82
5	374.25	76.5			38.14	19.07	9.54
6	194.25	67.	4.56		17.78	8.88	.77

Composition of food consumed.

No. of exp.	1	2	3	4	5	6
Days of exp.....	15	12	13	16	14	21
Nitrogen (lbs.) .	1.92	1.48	2.298	4.345	4.25	2.445
Phos. acid (lbs.)	.531	.425	.814	2.12	2.19	1.12
Potash (lbs.) ...	1.28	.949	1.078	2.299	2.14	1.43

Excrement recovered.

Nitrogen (lbs.) .	1.08	.994	1.8	2.83	1.59	1.758
Phos. acid (lbs.)	.35	.298	.665	1.466	1.08	1.106
Potash (lbs.) ...	1.089	.830	.963	1.06	.77	.541
Manure per ton..	$3.16	$2.65	$3.30	$3.49	$3.15	$4.17
Excrement, ton .	3.35	3.01	4.55	6.62	3.44	4.85

In the above experiment, fine-cut wheat straw of known composition was used for bedding in sufficient quantities to keep the sheep clean. The sheep were medium-sized grade Shropshires liberally fed on grain, beets and hay.

It will be noticed in No. 3 how the relatively more liberal grain ration raised the value of the excrements, as compared with 1 and 2, over $1.00 per ton; and it is also interesting to note in experiments 4, 5 and 6, how markedly the value of the excrements is affected by the character of the food. The average value of the manure of three pens of sheep, fed little more than a maintenance ration, as compared with the three pens fed more liberally on a narrower ration, is as follows:

TABLE XLII.

Average computed value of excrements of sheep.

Pens 1, 2 and 3	$3.64 per ton.
" 4, 5 " 6	4.97 " "
Average of all	$4.30 " "

TABLE XLIII.

Three sheep, fed 33 2-3 days standing on galvanized pans; weight of excrements, 723 lbs.

(Bull. 27, Cornell Exp. Sta., 1891.)

	Per cent.		Per ton.
Nitrogen	1.	at 15 cents,	$3.00
Phosphoric acid	.08	" 7 "	.11
Potash	1.21	" 4.5 "	1.09
			$4.20

TABLE XLIV.

Average percentage of fertilizing elements recovered in all experiments.

	Nitrogen, %	Phos. acid, %	Potash, %
Sheep	.62	.73	.66
Calves	.56	.39	.63
Pigs	.80	.73	.80

The preceding tables show that the total values and the percentages of fertilizing constituents vary, as might be expected. The percentage recovered with swine is larger than with sheep and calves. This would seem to indicate that swine digest and assimilate a larger amount of the carbohydrates and a less amount, taken together, of the other constituents, than either sheep or calves do. The amount of fertilizing elements recovered is dependent on so many conditions, as the power to assimilate food, the age and species, and the kind and quantity of surplus products produced by the animal, that only a general average can be reached, which must be amended as experiments throw more light on the subject.

Sheep have been so frequently used for conducting digestion and other experiments, that it was hoped when this book was begun that extended data

could be secured, but it is found that the digestion experiments furnish little material which is applicable to the manure problem, since, in order to conduct digestion experiments accurately, the animals used of necessity are placed under abnormal and uncomfortable conditions.

The following figures show the cost of food and computed value of manures of fattening lambs. Twelve lambs were fed in four lots. They were shorn in November and fed until April.

TABLE XLV.

Manurial value of the rations fed, allowing that 80 per cent was recovered in the excrements.—Pounds.

(Bull. 8, Cornell Exp. Sta., 1889.)

	Cotton-seed meal.	Bran.	Maize.	Timothy hay.	Mangolds.	Turnips.	Clover hay.
Lot III..			238	228	125	97	
Lot IV..	106	233			151	49	312
Lot V...	62	62	204	255	143	99	
Lot VI..	62	62	208	234			

	Cost of ration.	Manurial value.	Cost of ration, less value of manure.
Lot III (carbonaceous).........	$3.70	$1.12	$2.58
Lot IV (nitrogenous)	4.66	3.56	1.10
Lot V (intermediate, with roots)	4.78	2.10	2.68
Lot VI (" without ")	4.51	1.97	2.54
	$17.65	$8.75	$8.90

From the above, it appears that the computed value of the manure from fattening lambs, as compared with the cost of food, is as follows:

Cost of food..	$17.65
Value of manure	8.75

MANURE AND EXCREMENTS OF SWINE.

The following statistics give the percentages, amounts, and computed values of three constituents of the excrements and manure of pigs and mature swine.

TABLE XLVI.

Pig manure.

(9th Annual Report N. Y. State Exp. Sta.)

Ration about 75 per cent maize ensilage, 25 per cent bran and middlings

	Per cent.	Per ton.
Nitrogen	.54 at 15 cents,	$1.62
Phosphoric acid	.66 " 7 "	.92
Potash	.73 " 4.5 "	.65
		$3.19

Ration about 75 per cent maize on cob, 25 per cent bran and middlings.

	Per cent.	Per ton.
Nitrogen	.57 at 15 cents,	$1.71
Phosphoric acid	.83 " 7 "	1.16
Potash	.37 " 4.5 "	.33
		$3.20

TABLE XLVII.

Hogs fed on bone garbage and maize meal.

(Report for 1890, Conn. Exp. Sta.)

	Per cent.	Per ton.
Water	65.23	
Nitrogen	.58 at 15 cents,	$1.74
Phosphoric acid	.80 " 7 "	1.12
Potash	.10 " 4.5 "	.09
		$2.95

TABLE XLVIII.

Pig manure.—Two lots of pigs, four in each, fed standing on galvanized iron pans seven days. Lot 1 fed maize meal; lot 2 fed two parts maize meal and 1 of flesh meal.

(Bull. 27, Cornell Exp. Sta., 1891.)

Composition of excrements.

	Carbonaceous ration, Lot 1. Per cent.	Nitrogenous ration, Lot 2. Per cent.	Average, Per cent.
Nitrogen	.74	.92	.83
Phosphoric acid	.01	.06	.04
Potash	.58	.64	.61
Per ton	$2.94	$3.41	$3.18

The pigs used in these experiments were taken from two lots, one of which, for some time previous, had been feed a nitrogenous and the other a carbonaceous ration, and this accounts for the difference in the weights of the two lots when put on pans. The four pigs fed the carbonaceous ration weighed 426 lbs.; those fed a nitrogenous ration weighed 600 lbs.

TABLE XLIX.

Value of manure per year per pig of 150 lbs., fed on a narrow or nitrogenous ration.

Nitrogen	$2.64
Phosphoric acid	.08
Potash	.52
Per year	$3.24

Value of manure per year per pig of 150 lbs., fed on a wide or carbonaceous ration.

Nitrogen	$0.91
Phosphoric acid	.091
Potash	.183
Per year	$1.184

Computed value per year per 100 lbs. live weight.

Fed on a narrow or nitrogenous ration	$2.16
" " " wide " carbonaceous "	.79

TABLE L.

Amounts and value of manure produced by pigs fed for seven days, standing on large galvanized iron pans. Three pigs in each experiment.

(Bull. 56, Cornell Exp. Sta., 1893.)

Food consumed.

	Skim milk.	Maize meal.	Wheat bran.	Linseed meal.	Meat scraps.
Lot 1........	110 lbs.	64.5			32.1
" 2........	168 "	59.32			29.66
" 3........	135 "	4.57	4.57	6.86	

Average weight of pigs.

Lot 1	137 lbs.	Total weight, 411 lbs.
" 2....................	153 "	" " 459 "
" 3....................	111 "	" " 333 "

Amount of fertilizing material in food consumed.

	Nitrogen.	Phos. acid.	Potash.
Lot 1	4.698	2.29	.589
" 2............................	4.723	2.27	.624
" 3............................	1.34	.59	.322

Amount of fertilizing material recovered.

Lot 1	3.217	1.70	.534
" 2............................	3.481	1.45	·472
" 3............................	1.330	.48	.323

	Excrements. 1,000 lbs. live animal per day.	*Value of excrements.* 1,000 lbs. live animal per day.
Lot 1........................	108.9 lbs.	$0.2106
" 2........................	75.8 "	.186
" 3........................	56.2 "	.104

Composition of pig manure (unpublished).

	Water, per cent.	Nitrogen, per cent.	Phos. acid, per cent.	Potash, per cent.	Per ton.
Lot 1	78.47	.88	.48	.29	$3.48
" 2	74.58	.91	.40	.28	3.46
" 3	69.34	.74	.30	.40	2.76

It is seen in what a marked degree the food consumed effects the quality. The nitrogenous produced three-fold more excrements than the carbonaceous rations.

TABLE LI.

Summary of computed values of pig manure.

	Excrements per ton.	Manure per ton.
New York Experiment Station (Geneva)		$3.19
" " " " "		3.20
Connecticut " "		2.95
Cornell " "	$2.94	
" " "	3.41	
" " "	3.18	
" " "		3.48
" " "		3.46
" " "		2.94
Average of manure		3.20
" " excrements		3.18

ANALYSES OF THE EXCREMENT OF FOWLS.

TABLE LII.

Composition of fresh hen manure.

(Cornell Exp. Sta. 1891, 1892, unpublished.)

Mixed ration, fed equal parts corn and oats.

	Per cent.	Per ton.
Water	46.84	
Nitrogen	1.38	$4.14
Phosphoric acid	.50	.70
Potash	.41	.37
		$5.21

Carbonaceous ration, of nothing but corn.

	Per cent.	Per ton.
Water	26.74	
Nitrogen	1.10	$3.30
Phosphoric acid	.24	.34
Potash	.27	.24
		$3.88

Nitrogenous ration, two parts wheat to one cracked peas.

	Per cent.	Per ton.
Water	24.43	
Nitrogen	1.10	$3.30
Phosphoric acid	.47	.66
Potash	.29	.26
		$4.22

Mixed ration,* equal parts corn and oats.

	Per cent.	Per ton.
Water	39.67	
Nitrogen	.748	$2.24
Phosphoric acid	.22	.31
Potash	.23	.22
		$2.77

TABLE LIII.

Hen manure, sun dried.

(Cornell Exp. Sta., 1892, unpublished.)

	Per cent.	Per ton
Water	4.25	
Nitrogen	2.	$6.00
Phosphoric acid	.85	.63
Potash	.35	.31
		$6.94

*Plaster 2 lbs. to 1 lb. of manure added to prevent loss of nitrogen.

TABLE LIV.

Fresh hen manure.

(Bull. 84, New Jersey Exp. Sta.)

	Per cent.	Per ton.
Water	55.	
Nitrogen	1.09 at 15 cents,	$3.27
Phosphoric acid	.92 " 7 "	1.29
Potash	.45 " 4.5 "	.40
		$4.96

TABLE LV.

Manure of fowls, fresh.

(8th Annual Report N. Y. State Exp. Sta.)

Pen 6.	Per cent.	Per ton.
Water	59.7	
Nitrogen	1.40 at 15 cents,	$4.20
Phosphoric acid	.92 " 7 "	1.28
Potash	.32 " 4.5 "	.28
		$5.76

Pen 7.	Per cent.	Per ton.
Water	55.3	
Nitrogen	1.14 at 15 cents,	$3.42
Phosphoric acid	.72 " 7 "	1.00
Potash	.25 " 4.5 "	.22
		$4.64

Pen 6, average value per fowl, 14 cents per year.
" 7, " " " " 10 " " "

TABLE LVI.

Hen manure, air-dried.

(Same as above.)

Nitrogenous ration.

	Per cent.	Per ton.
Water	7.44	
Nitrogen	1.82 at 15 cents,	$5.46
Phosphoric acid	2.21 " 7 "	3.09
Potash	1.11 " 4.5 "	1.00
		$9.55

Carbonaceous ration.

	Per cent.			Per ton.
Water	7.13			
Nitrogen	1.53	at 15	cents,	$4.59
Phosphoric acid	1.92	" 7	"	2.68
Potash	1.01	" 4.5	"	.90
				$8.17

TABLE LVII.

Another analysis of hen manure, fresh.

(7th Annual Report Mass. Exp. Sta.)

	Per cent.			Per ton.
Water	45.73			
Nitrogen	.79	at 15	cents,	$2.37
Phosphoric acid	.47	" 7	"	.65
Potash	.18	" 4.5	"	.16
				$3.18

Air-dried.

	Per cent.			Per ton.
Water	8.35			
Nitrogen	2.13	at 15	cents,	$6.39
Phosphoric acid	2.02	" 7	"	2.82
Potash	.94	" 4.5	"	.84
				$10.05

TABLE LVIII.

Another Massachusetts analysis of hen manure, fresh.

(Bull. 37, Mass. Exp. Sta.)

	Per cent.			Per ton.
Water	58.98			
Nitrogen	1.20	at 15	cents,	$3.60
Phosphoric acid	1.	" 7	"	1.40
Potash	.32	" 4.5	"	.28
				$5.28

TABLE LIX.

Fresh hen manure.

(Report 1890, Conn. Exp. Sta., page 88.)

	Per cent.		Per ton.
Water	34.87		
Nitrogen	.56	at 15 cents,	$1.68
Phosphoric acid	.35	" 7 "	.49
Potash	.36	" 4.5 "	.32
			$2.49

The following averages of value and water content in hen manure are made from the above tables:

TABLE LX.

	Water, per cent.	Per ton.
Fresh manure	55.	$4.96
" " pen 6 (N. Y. State Sta.)	59.7	5.76
" " " 7 " " "	55.3	4.64
" " (Mass., 2)	52.35	4.23
" " "	34.87	2.49*
" " (Cornell, 4)	34.42	4.02
Average	48.61	$4.35

	Water, per cent.	Per ton.
Nitrogenous ration, air-dried (N. Y. State Sta.)	7.44	$9.55
Carbonaceous ration, " " " "	7.13	8.17
Massachusetts, "	8.35	10.05
Cornell, "	4.25	6.94
Average	6.79	$8.68

TABLE LXI.

Pigeon manure.

(Storer, Agriculture, i, p. 369.)

Excrement imported into England from Egypt.

	Per cent.	Per ton.
Water	6.75	
Nitrogen	6.5	$19.50
Phosphoric acid	8.	11.20
Potash	.50	.45
		$30.15

* Sample contained about 10 per cent of earth.

Wein found in excrement taken from church steeple.

	Per cent.	Per ton.
Water	11.	
Nitrogen	2.25	$6.75
Phosphoric acid	2.	2.80
Potash	5.5	4.95
		$14.50

TABLE LXII.

Analysis of pigeon excrements produced in the United States.

(Handbook of Experiment Station Work.)

	Per cent.	Per ton.
Moisture	10.	
Nitrogen	3.20	$9.60
Phosphoric acid	1.90	2.66
Potash	1.	.90
		$13.16

Fresh hen manure appears to be worth nearly twice as much as cattle manure. This is due in a large measure to less moisture content; while the latter has 74 per cent, the former contains but 51.59 per cent of moisture, on an average. Computed at the same moisture content, the hen manure would be worth $2.35 per ton, against $2.46 for the cattle manure (page 153).

Usually hen houses are kept clean by sprinkling chaff, dust or gypsum on the floors and roosts. In such cases it may easily happen that the litter may be so abundant that the value of the manure is reduced to nearly that of cattle manure. On the other hand, unmixed hen manure, air-dried, may be worth four times as much as an equal weight of cattle manure. Such concentrated manures may be, and usually are, worth more per unit of fertilizing material than unconcentrated ones, if judiciously

used, since the value of manures and fertilizers is dependent, in part, on their immediate availability, especially of their nitrogenous compounds. If the nitrogen in manures is available only in the advanced stages of the plant's growth, and is present in abundance, it may produce a positive injury, while if available in the early stages, it is likely to be very beneficial. Since hen manure, especially that which is unmixed with litter, and is air-dried, contains a high percentage of readily available nitrogenous compounds, these compounds are of more value per unit than are those contained in the slower-acting cattle manure. It may be concluded that high-grade, quickly available manures and fertilizers are more valuable, unit for unit of plant-food, than those which are slowly available, provided, always, that they are used with judgment.

MISCELLANEOUS STATISTICS OF ANIMAL MANURES.

The following tables were condensed and compiled by A. Hebert from the experiments conducted by Andoynaud and Zacharewicz, and Müntz and Girard. (Contribution a l'étude du Fermier de Ferme.—Ann. Agron., II., (1885), pp. 129, 337. Reported in Experiment Station Record, v., page 142.)

TABLE LXIII.

	Nitrogen, per cent.	Phos. acid, per cent.	Potash, per cent.	Value per ton.
Horse urine	1.52		.9	$5.37
Horse solid excrement	.55	.35	.1	2.23
Cow urine	1.05		1.36	4.37
Cow solid excrement	.43	.12	.04	1.49

Amount of fertilizing material, solids and liquids, voided per animal daily.

	Nitrogen.	Phos. acid.	Potash.	Value.
Horses	.342 lbs.	.131 lbs.	.112 lbs.	$0.065
Cows............	.467 "	.071 "	.294 "	.088

TABLE LXIV.

Daily amounts of sheep and pig manure.

	Nitrogen.	Phos. acid.	Potash.	Value per ton.
Sheep (Müntz and Girard)	.51 %	.31 %	.87 %	$2.74
	.023 lbs.	.014 lbs.	.039 lbs.	
Pigs (Boussingault)......	.0326 "	.0246 "	.50* "	1.50

TABLE LXV.

Summary of above tables calculated per year in pounds.

	Nitrogen.	Phos. acid.	Potash.	Per year.
Horse	125.22 lbs.	47.83 lbs.	43.21 lbs.	$24.06
Cow.........	170.63 "	26.01 "	107.58 "	32.25
Sheep	8.40 "	5.6 "	14.33 "	2.29
Pig..........	11.90 "	10.58 "	11.90 "	3.06

TABLE LXVI.

Bat manure.

Nine analyses from various stations give the following average.

	Per cent.	Per ton.
Nitrogen......................................	8.5	$25.50
Phosphoric acid...............................	5.95	8.33
Potash..	1.14	1.02
		$34.85

TABLE LXVII.

Barnyard manure.

(Bull. 9, Mass. Hatch, 1890. No particulars given.)

	Per cent.
Moisture	70.16
Nitrogen	.486
Phosphoric acid	.553
Potash	.614

* Estimated.

	Lbs. in a ton.			
Nitrogen	9.72	at 15	cents,	$1.46
Phosphoric acid	11.06	" 7	"	.77
Potash	12.28	" 4.5	"	.55
				$2.78

TABLE LXVIII.

Barnyard manures—another account.

(Bull. 14, Mass. Hatch, 1891.)

	Per cent.			Per ton.
Moisture	67.28			
Nitrogen	.388	at 15	cents,	$1.16
Phosphoric acid	.289	" 7	"	.40
Potash	.387	" 4.5	"	.34
				$1.90

TABLE LXIX.

Farmyard manure (Voelcker).

	Fresh, per cent.	Rotted, per cent.			Fresh, per ton.	Rotted, per ton.
Nitrogen	.149	.297	at 15	cents,	$0.45	$0.89
Phosphoric acid	.299	.382	" 7	"	.42	.53
Potash	.573	.446	" 4.5	"	.52	.40
					$1.39	$1.82

TABLE LXX.

Mixed farmyard manures (D. Anderson, Scotland).

	Per cent.			Per ton.
Nitrogen	.38	at 15	cents,	$1.14
Phosphoric acid	.31	" 7	"	.43
Potash	.32	" 4.5	"	.29
				$1.86

TABLE LXXI.

F. J. Lloyd estimates from various data that an average ton of farmyard manure would contain—

Nitrogen	12 lbs.	at 15	cents,	$1.80
Phosphoric acid	5 "	" 7	"	.35
Potash	11 "	" 4.5	"	.49
				$2.64

CHAPTER VIII.

THE WASTE OF MANURES.

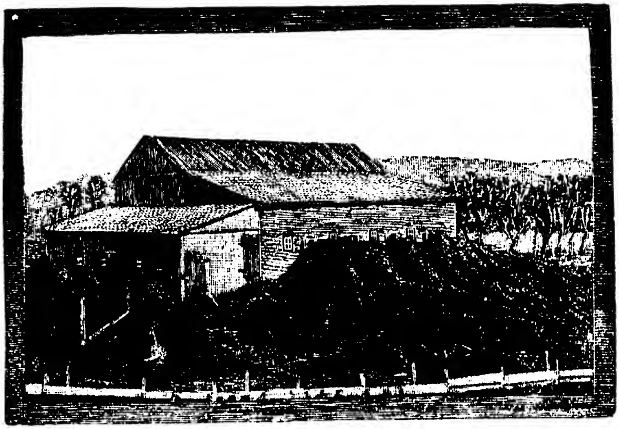

Fig. 29. Baptism of farm manures. From a photograph taken in Minnesota.

Fig. 30. A typical old-time farmyard. From a recent photograph taken in central New York.

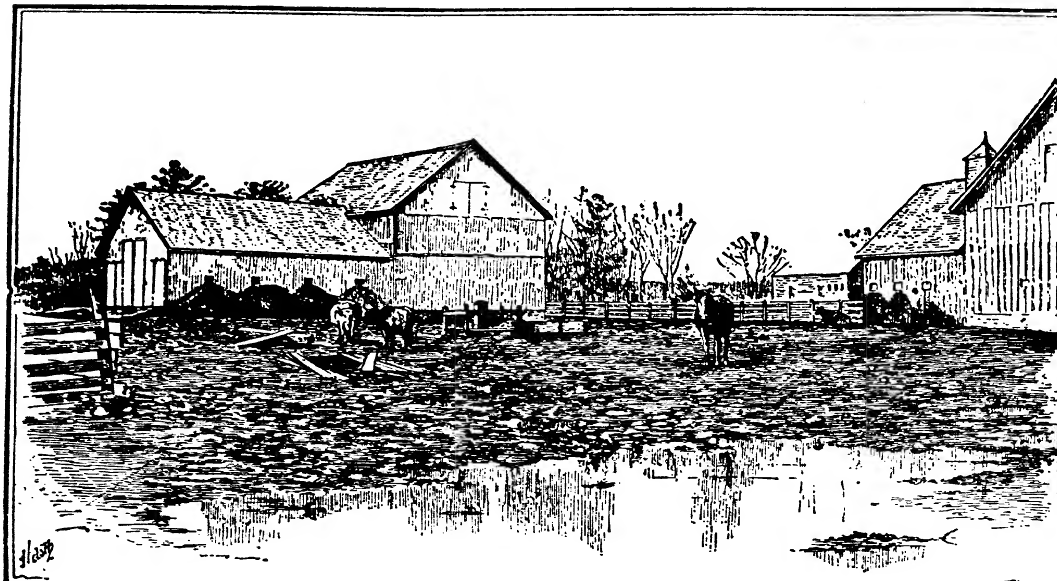

Fig. 31. The unprofitable barnyard. From a photograph taken in New York.

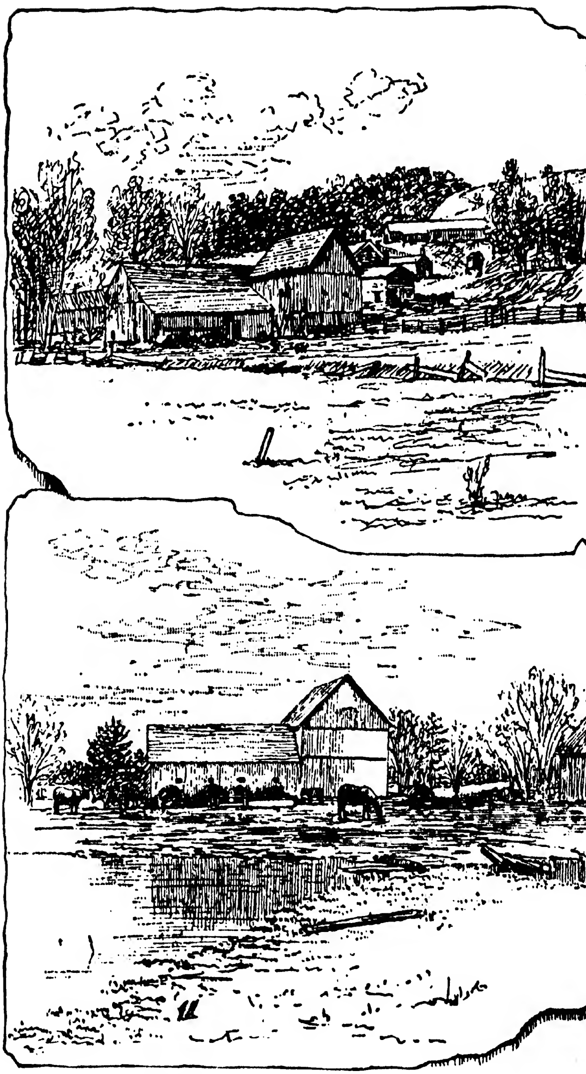

Fig. 32. Showing the effective means which the farmer employs to advertise his shiftlessness and his lack of appreciation of home resources.

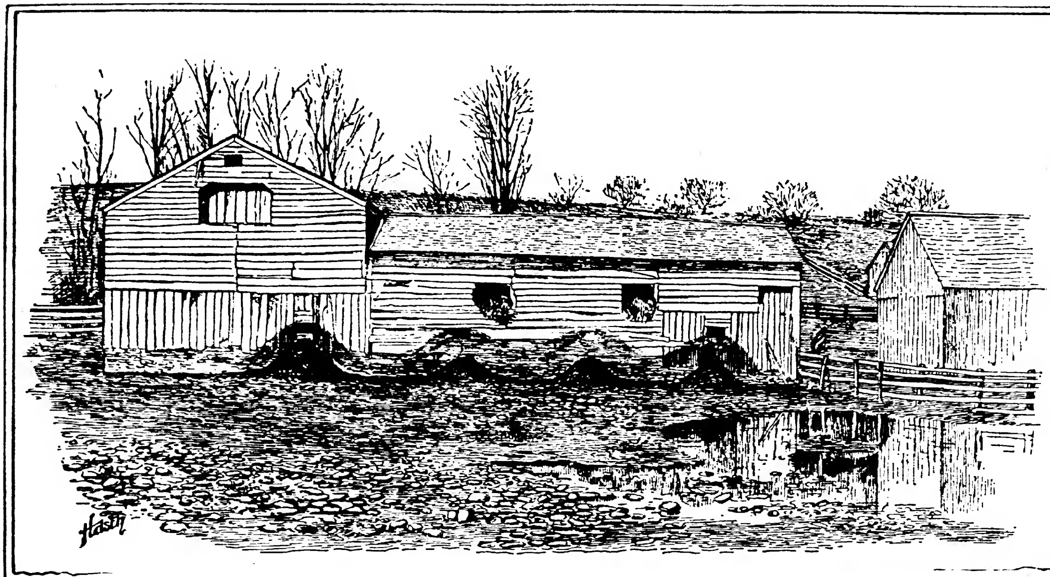

Fig. 33. From a photograph of the "good old ways" of our fathers, which the sons still admire.

Fig. 34. A Japanese student's conception of the wasting of farm manures. Adapted from a sketch on an examination paper at the Cornell University.

CHAPTER IX.

THE CARE, PRESERVATION AND APPLICATION OF MANURES.

THE amounts of manures and excrements which various species of animals produce, and also their percentage composition, have already been shown. It is impossible to set forth their true value. Notwithstanding this, it is certainly known that they are of enough value to justify painstaking effort to learn how best to husband them until used, the most appropriate time to apply them, and the crop likely to receive the greatest benefit from them.

LOSS IN MANURES DUE TO WEATHERING AND EXPOSURE.

If manures are sheltered, no loss is sustained from leaching by the passage of rain water through them, but loss may come from other causes. Manures exposed for a time may not suffer deterioration from the rain which falls upon them, but rather be benefited, as in the case of horse manure, which tends to heat rapidly if not kept moist. When a superabundance of water from the eaves of the barn falls upon it, or the layer or pile of manure is shallow, a single

heavy shower may cause leaching. The only safe method is to control the conditions, in order that the minimum of loss is sustained. Whenever an abundance of straw or other coarse bedding material is at hand, and when the horns are removed from the cattle or are prevented from growing, covered yards are found to be entirely satisfactory. In these the stock may take mild exercise and be watered, while at the same time they tramp the manure, and prevent its too rapid heating. If gypsum is distributed occasionally over the surface, the conditions of both the yard and the manure will be benefited.

A yard forty by sixty feet suffices for twenty to twenty-five full-grown cows. Covered barnyards give opportunity to control conditions, so that there will be no loss from scattering the manure, from tramping it into the mud, from leaching, from too rapid decomposition, and from escape of the liquid manure; while they furnish a most comfortable place for the animals to stretch their limbs while their stables are being aired, to quench their thirst in a comfortable atmosphere, with water brought to a temperature, in winter, of 98° Fahrenheit; and they give opportunity for removing the manure when most convenient and when the roads and fields are in suitable condition. Then, too, the manure is removed without handling as much rain water as manure, thereby preventing the thoughtless farmer from making a useless effort to irrigate his fields by the aid of a manure-fork.

Manure platforms or shallow, uncovered, cemented pits are sometimes built near the stables, in which

all manures are stored until wanted. Usually the liquid manures, augmented by the rain, make cisterns necessary for their storage, or the pit will overflow. Unless absorbents are present in liberal amounts, the water added by exposure is of no benefit, while it most unnecessarily increases the cost of removing the manures.

Distributing liquid manure, mixed or unmixed with rain water, by the means of water-tight tanks and sprinkling attachments, is seldom found to be satisfactory, and should be avoided if sufficient absorbents can be secured to change the mass to a semi-solid state, suitable for handling with a shovel. The free use of bedding not only absorbs the liquid voidings, but tends to promote cleanliness in the stable, and the comfort of the animals. Whatever method is adopted, three things should be kept clearly in mind: comfort and health of the animals, conservation of the manures, and economy of labor in removing them to and from their temporary storage place. In many cases fully a third of the value of the manures is expended on them between the stable and the field.

The practice of removing manures from the stable directly to the field is a good one whenever it can be carried out. Unfortunately there are times when the fields are over-moist, the lanes impassable, time lacking, and no suitable place ready to spread the manure, and for such emergencies some storage receptacle, even though a small one, should be provided. The open manure barnyard is destined to pass away, and needs only a few vigorous kicks to hasten its departure.

Manure, if placed in deep piles and cared for, may be improved by partial rotting without sustaining much loss. Frequently the loss is fully balanced by the increased percentage of available plant-food and by the improved texture of the manure.

The need of caring for manures is emphasized by the following tables, which give the results of investigations conducted in 1889 at the Cornell Experiment Station (Bulletin XIII.). The values of nitrogen, phosphoric acid and potash have been computed to correspond with those in previous chapters. The following is one day's product of nine horses:

Total weight of excrements, solid and liquid......	491. lbs.
Weight of straw bedding..........................	38.5 "
Total..	529.5 "

This material was lightly packed in a wooden box, not water-tight, surrounded with manure, and left exposed from March 30 to September 30. At the end of six months it was found to have sustained the following losses:

A ton of this manure, computed as in previous tables, was worth $2.30 per ton when fresh; after six months' exposure, $1.32. Loss, $0.98 per ton, or 42.6 per cent.

In 1890, 4,000 pounds of manure from the horse stables, composed of 3,319 pounds of excrements and 681 pounds of straw, were placed out of doors in a compact pile and left exposed from April 25 to September 22, at the end of which time the total

weight had decreased to 1,730 pounds. The tabular results were as follows:

	April 25, lbs.	Sept. 22, lbs.	Loss, per cent.
Gross weight	4,000	1,730	57
Nitrogen	19.60	7.79	60
Phosphoric acid	14.80	7.79	47
Potash	36	8.65	76
Per ton	$2.80	$1.06*	

Five tons of cow manure, composed of 9,278 pounds of excrements mixed with 422 pounds of wheat straw, were exposed in a compact pile for the same period as the horse manure was, and under similar conditions, except that 300 pounds of gypsum were mixed with it. The outcome was as follows:

	Lbs. at beginning.	Lbs. at end.	Loss, per cent.
Gross weight	10,000	5,125	49
Nitrogen	47	28	41
Phosphoric acid	32	26	19
Potash	48	44	8
Per ton	$2.29	$1.60*	

Manures may lose a large percentage of their valuable constituents and yet be worth more *per ton* than they were before the loss occurred. Consider, for instance, the five tons of cow manure which contained at the beginning 47 pounds of nitrogen, or 9.4 pounds per ton, and at the end of the investigation 28 pounds, and note that this 28

*Value on September 22 of an amount of manure which weighed 2,000 lbs. on April 25.

pounds was contained in 2.56 tons, instead of in the original 5 tons. While the total loss of nitrogen was 41 per cent in the exposed manure, the sample contained 10.9 pounds of nitrogen per ton, or 1.5 pounds per ton more than the fresh manure.

The following table gives in brief the results of many experiments at Cornell in exposing manures during two years:

TABLE LXXII.

	Per ton at beginning.	Loss, per ton.	Loss, per cent.
1889, horse manure in loose pile	$2.30	$1.32	42.6
1890, " " " " "	2.80	1.74	62.
1890, cow " " " "	2.29	.69	30.
1889, mixed manure compacted in box	2.24	.23	8.7

The rainfall in 1890 was unusually abundant, as is shown by the following table:

TABLE LXXIII.

Rainfall during the progress of the experiment.

Month.	1890, inches.	Ave. for 12 years, inches.	Excess +; deficiency —; inches.
April	3.34	2.	+1.34
May................................	6.60	3.69	+2.91
June................................	4.94	3.73	+1.21
July	1.24	3.92	—2.68
August	4.92	3.18	+1.74
September	6.62	2.79	+3.83
Total..............................	27.66	19.31	+8.35

From October 1, 1884, to March 2, 1885, 191¼ tons of mixed manure from horses, cattle and sheep accumulated in the covered barnyard at Cornell University. This manure was the product of 12

spring calves, 7 winter calves, 24 cows, 1 bull, 12 horses and 1 colt for the five months. It was well compacted by the tramping of the cattle, which were kept for the greater part of each day in the covered yard. A large number of samples of about ten pounds each was taken from the undisturbed mass by cutting out solid cubes. These were put together, chopped, mixed, divided and subdivided, and a sample was taken for analysis. A similar determination had been made in 1883–4. The following table gives the results, in separate columns, of the two years' determinations:

TABLE LXXIV.

	1884–5, per cent.	1883–4, per cent.
Moisture	75.57	72.95
Nitrogen	.68	.78
Phosphoric acid	.29	.40
Potash	.70	.84

In 1895, an investigation was made at the Cornell Experiment Station to determine the accuracy of sampling manures. Seventy-six loads of manure, which had accumulated in a covered barnyard from July to October, were sampled as the manure was removed, by placing every thirtieth forkful in one of three boxes,—the first forkful in box No. 1, the next in No. 2, and the next in No. 3. When the work was completed the sample boxes contained about one ton each. Each of these large samples was separately mixed and roughly fined and divided into two equal parts, one of which was saved, the other discarded. The sample saved was again mixed

and fined, and divided as before. As the samples became smaller by discarding one-half, more and more pains was taken to chop and fine the material by means of sharpened spades and axes. When the original samples were reduced to about one bushel each, the final samples were taken for analysis. The following table shows the composition of the samples:

TABLE LXXV.

	Box 1, per cent.	Box 2, per cent.	Box 3, per cent.
Moisture	63.34	62.85	64.02
Nitrogen	.87	.86	1.01
Phosphoric acid	.59	.60	.53
Potash	.15	.14	.14

Studies were undertaken by Müntz and Girard from 1883 to 1887,* to determine the loss or difference of nitrogen between the amounts of food consumed by various classes of animals and the amounts recovered in manure, when the excrements were fresh, and when left in the stables for different periods of time. Their figures (which are given in Table LXXVI.) do not represent the true losses due to exposure, as no account was taken of the loss or gain in weight of the animals. Even if the animals had been weighed at the beginning and end of the experiment, little would have been gained, since the weight of animals varies widely from day to day. The amount of water drunk by a mature cow in milk may vary from a few to seventy-five pounds daily. Steers fattened on air-dried corn and hay add from 5

*Experiment Station Record, v. 154; quoted from "Les Engrais."

to 15 per cent of water to the dressed carcass in a few weeks when turned on succulent pastures, and yet may gain little or nothing in live weight. Animals producing young, wool or milk use more or less of the nitrogenous compounds in their food in addition to those required for maintenance, and hence could not return in their excrements all of the potential nitrogen contained in their rations.

TABLE LXXVI.

Losses in manure exposed to air.

Manure from sheep.

	Fresh, lbs.	After 6 months, lbs.	Loss, lbs.
Weight of manure	15,784.93	9,281.36	
Dry matter	5,160.96	3,869.07	1,291.89
Total nitrogen	96.34	85.31	11.02
" phosphoric acid	97.88	79.14	18.74
" potash	269.84	211.64	58.20

Manure from cows.

Weight	11,748.31	7,209.04	
Dry matter	5,156.56	3,315.72	1,840.84
Total nitrogen	95.02	72.09	22.93
" phosphoric acid	46.95	43.65	3.3
" potash	170.40	144.18	26.22

In the preceding tables, it will be noticed that the nitrogen and potash are lost in much larger proportions than the phosphoric acid is. Dry earth would largely prevent the loss of both nitrogen and potash. It has been assumed by good authorities that, on an average, fattening animals return in their excrements 90 per cent, cows in milk and half-mature growing animals 70 per cent, young calves fed on milk and other easily digested foods 10 to 20 per

cent, and animals not increasing in weight or furnishing a surplus product nearly 100 per cent of the nitrogen, phophoric acid and potash of their food. It is seen how difficult it is to determine the losses due to exposure of manures by noting the difference between the amounts of constituents fed and the amounts recovered.

The foods fed to certain animals were analyzed, and also the resulting manure, the loss of nitrogen being found by differences in some cases; in others, the actual loss of the manure after it was produced was determined. In horse stalls, where the solids were taken up as soon as dropped, and the urine absorbed by straw on cement floors and taken up daily, 71.3 per cent of the nitrogen was recovered. In cow stables, where the excrements were removed daily, 72.8 per cent was recovered; when removed twice a week, 67.64 per cent. In sheep-pens bedded with clean straw, and the manure allowed to accumulate during the period of the experiment, the following amounts were recovered:

TABLE LXXVII.

Losses in sheep-pen manure.

	Period of experiment.	Nitrogen recovered, per cent.
June 15–July 7	23 days	49.8
July 8– " 31	23 "	44.7
Jan. 19–Feb. 9	21 "	54.1
Feb. 9–Mar. 2	21 "	56.2
Mar. 20–Apr. 10	21 "	55.7

A pile of fresh horse manure, composed of 491 pounds of solid and liquid excrements and 38.5

pounds of bedding (total 529.5 pounds), was placed in a wooden box, not water-tight, and surrounded with manure of a similar character. The following table gives the composition of the manure when fresh and after it was exposed six months:

TABLE LXXVIII.

(Bull. 13, Cornell Exp. Sta., 1889.)

	Fresh, per cent.	After 6 months' exposure, per cent.
Moisture	70.79	81.74
Nitrogen	.51	.46
Phosphoric acid	.21	.15
Potash	.53	.31
Total weight of manure	529.5 lbs.	372 lbs.

Value of one ton fresh manure	$2.30
" " the same after 6 months' exposure	1.32
Loss	42 per cent.

A block of undisturbed manure one foot deep, of cattle and horse excrements mixed with straw bedding, kept under cover and packed solidly by the tramping of cattle as it was thrown from the Cornell stables, was placed in a close-fitting galvanized iron pan with a perforated bottom, and left out of doors from March 31 to September 30. The following table shows the loss which took place:

TABLE LXXIX.

	Loss, per cent.
Nitrogen	3.2
Phosphoric acid	4.7
Potash	35

Computed value of one ton before exposure	$2.21
Value of the same ton after exposure	2.01
Loss per ton	9.05 per cent

The compacted manure shows a far less loss by exposure than the losely piled manure does.

Sheldon comes to the following conclusions, after conducting experiments similar to these at the Kansas Experiment Station: "The moral which the experiments plainly emphasize is, that farmyard manures must be hauled to the field in the spring; otherwise the loss of manure is sure to be very great, the waste in the course of six months amounting to fully one-half the gross manure, and nearly 40 per cent of the nitrogen that it contained."

The New York State Experiment Station has made somewhat extended experiments in the loss of manures, the results of which are here briefly summarized:

A pile of cow manure weighing 3,298 pounds lost in weight in one year 65.19 per cent, and in bulk 50 per cent.

An old compost heap, of which muck was the leading ingredient, was simultaneously exposed for the same length of time, and lost 29.45 per cent in weight, and 28.6 per cent in bulk.

The manure lost 46.6 per cent of its manurial constituents, and the muck 21.45 per cent of its nitrogen, and almost nothing of its potash and phosphoric acid.

The writer of Bulletin 23, September, 1890, says (p. 325): "Great losses of nitrogen from manures are usually associated with drying and burning out, hence we must consider these results to be under rather than over what may be expected in average years."

At the North Carolina Experiment Station, a miniature pile of manure exposed for three weeks showed a loss of 3.36 per cent of ammonia, which is equal to 2.77 per cent of nitrogen. (Bulletin 63, p. 113.)

Determinations made of the leachings from a manure pile by the Massachusetts Experiment Station showed that notwithstanding the presence of 93 per cent of water, the leachings were worth $2.94 per ton. (Eleventh Annual Report, 1893, p. 345.)

Sheep manure at the Cornell Experiment Station, 1893, sun-dried in the spring for forty-two days in ten-pound lots, showed a loss when unmixed with gypsum of 38.9 per cent, and when mixed with gypsum a loss of 26.3 per cent of nitrogen. (From unpublished material.)

A field test of the value of housed and unhoused manures was made from 1891 to 1893 in Utah, which showed that the plats treated with housed manures gave an increase in grain of 6.64 per cent over those treated with unhoused manures. (Utah Experiment Station, Fourth Annual Report, p. 160.)

The experiments of J. R. Schiffer (Zeitsch. d. landw. Ver. f. Rheinpreussen, 1892, pp. 43, 44), made with barnyard manure preserved by the use of superphosphate (gypsum,) and unpreserved manure, gave the following results:

	Potatoes, bus.	Barley, bus.
Preserved manure	247	42.1
Unpreserved manure	232	34.5
Difference	15	7.6

Potatoes upon which the treated manure was used

averaged 21.6 per cent of starch, and those where the other was used averaged 17.9 per cent. The author calculates a net increase from the use of preserved manure over the unpreserved of about $35 per acre in the trial with potatoes. These results are for the first year after the application of the manure. In the last experiment, no account appears to have been taken of the fertilizing material contained in the superphosphate; and while the material used for preserving the manure without doubt conserved the nitrogen, yet it is barely possible that the increased yield, due to the preserved manure, was the result in part of the phosphate, and not wholly attributable to the nitrogen which was conserved.

The system of feeding animals in box stalls, allowing the manure to accumulate, tends to conserve the valuable constituents. An analysis by Biernatzki shows the difference between manure preserved after this plan and by the common heap method to be as follows:

	Moisture, per cent.	Total nitrogen, per cent.	Phos. acid, per cent.	Potash, per cent.
Heap method	83.78	.47	.26	.43
Improved method	76.54	.67	.31	·76

COVERED MANURE YARDS.

At many a farmstead conditions are found which at first glance appear to have been brought about by a well-laid plan persistently carried out for wasting manures, thereby obviating the labor and expense

of removing them to the fields. The manures are thrown out of windows under the great eaves of the wide-extending roof, or out of the stable door, where, during a portion or all of the rainy months, they are leached into the streams and the fine particles washed over large areas or partially burned by self-generated heat, and robbed of the larger portion of their potential nitrogen. Washed by the rains, dried by the winds, burned by slow combustion, rooted over by swine, punched into the mud by the hoofs of animals, and scratched into the fence corners by the ever-industrious dung-hill fowls, is it any wonder that this mixture of mud, water and leached manure is described as the "attenuated corpse from which the spirit has long since departed"?

Many barnyards contain not less than one-fourth of an acre (100 x 110 feet), upon which falls annually, in central New York (where the annual rainfall is 32 inches), 1,812,800 pounds, or 900 tons, of water. In addition to this, from the eaves of most barns come floods of water, which add to the forces of destruction and deterioration already present.

The following illustrations are designed to show how easily the manures from the stables may be preserved from waste until time and suitable conditions in the fields make it convenient to remove them.

Fig. 36 shows how easily the unsightly conditions which are shown in Chapter VIII. can be avoided, and how the losses which occur from the methods there shown may be prevented.

The larger and more convenient manure recepta-

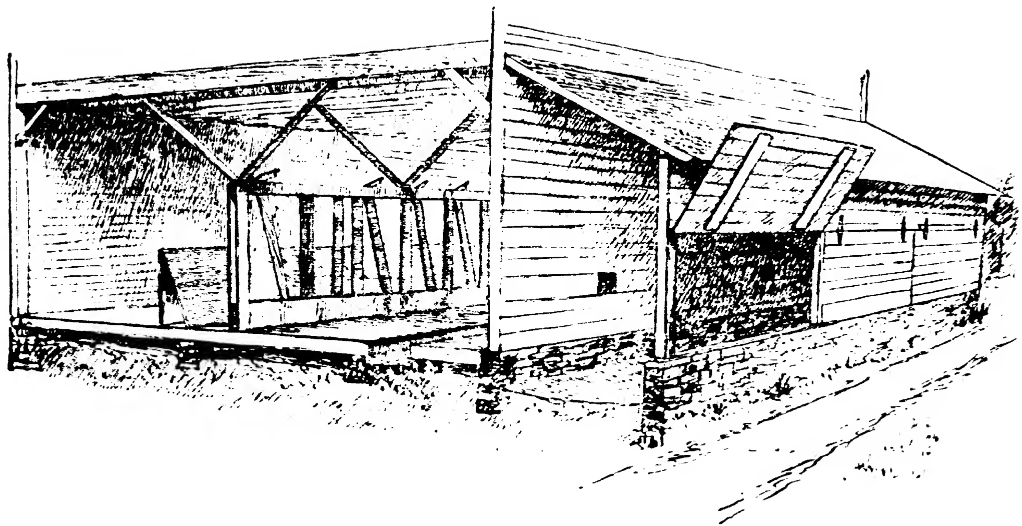

Fig. 36. A handy and economical stable, with cattle-racks, a manure trough (behind which is a walk), and a small covered area at the rear, with a hollowed cement bottom, for the storage of the manure.

cle shown in Figs. 37, 38 and 39 is easily and cheaply built, and well adapted, when somewhat enlarged in breadth and height, to not only shel-

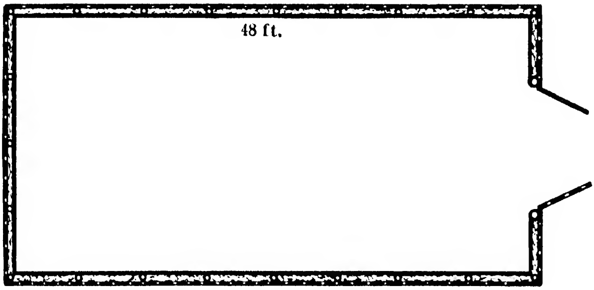

Fig. 37. Plan of a manure shed.

tering the manures, but the straw stack as well. It also provides suitable and sheltered quarters for the animals while being watered, and a place in which they may take all the exercise required during the colder months of the year while their quarters are being aired and cleaned. Here, too, may the two extremes of over and under-exercise be avoided.

To turn milch cows and calves out from warm stables into the bleak, piercing winter wind for even an hour, and force them to travel to some distant stream and drink ice-cold water or do without, is not only cruel but unprofitable. To offer the excuse that animals need exercise, and, therefore, this is a good way of compelling them to take it, makes the practice none the less reprehensible. The custom of fastening animals in uncomfortable stanchions in the

fall, and keeping them there until spring on hard unbedded or half-bedded floors, without any chance to take a breath of fresh air or to stretch their limbs, is a practice scarcely less reprehensible than the other. The better system would appear to lie between these two uncomfortable methods. If no suitable basement, or open shed which could be inclosed, is at hand, a larger or smaller structure than that shown in the figures, built as a wing to the barn and over the great barn doors, would serve most admirably in lieu of the wasteful and cruel open barnyard.

The plans are modeled after a large horse-barn built by the author some years since. Such a structure is not only inexpensive but durable, and may be made to conserve the manures of the farmstead in a most economical way. The floor may be of

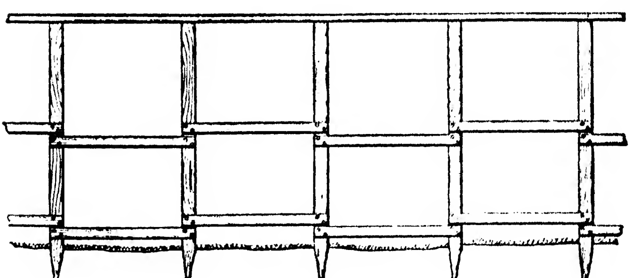

Fig. 38. Frame structure of the manure shed.

pounded clay or of grout. The round posts, set six feet apart and about two feet in the ground to give them stability while erecting the structure, are of any length desired. After being set in line, much the

same as shorter fence posts are, two tiers of girts 2 x 4 are spiked to their outer surfaces, and a 2 x 6, spiked on top of the posts, after they have been sawed off, serves for plate (Fig. 38). The outer boarding is put on vertically, the inner boarding

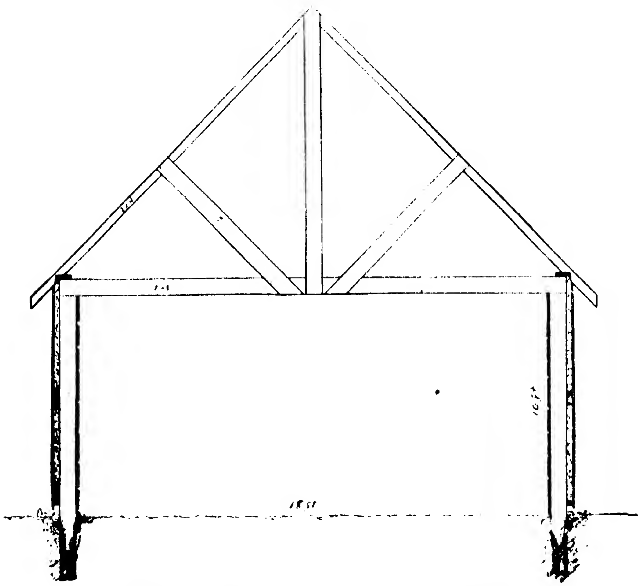

Fig. 39. Frame structure of the manure shed.

horizontally, and the space between filled tightly with straw. Good shingles should be used to cover the building, for no matter how inexpensive a structure may be, it is economy to keep it covered with a water-tight roof. When the posts have become weakened by decay, they may be sawed off at the ground

and flat foundation stones, four to six inches thick and eighteen inches square, placed under them.

If the structure were wider than that shown, it would require center supporting posts, and if it had two stories, the upper one used to store straw, then the building should be tied together by joists placed two feet apart, supported by a summer (a timber under center of joists) and by center posts (Fig. 39). A structure of this character will be much drier than one built of stone or even of double-boarded paper-fortified wooden walls, and fully as warm if the roof space is filled with straw, and far cheaper.

A due regard for the comfort and productive power of the animals, the fertility of the land, the economy of labor, and the conscience of Christian farmers makes it incumbent upon every tiller of the soil to provide comfortable quarters for all animals, and ample and suitable room for the storage of all farm products until wanted, including manures and all implements and tools, that the farm and its surroundings may have the appearance of neatness and thrift, that the productive power of the land may be preserved and increased, and that farming may be made, as it deserves to be, the most delightful of all professions.

THE APPLICATION OF MANURES.

In a country varying so widely as ours does in climate, in the crops raised, in markets, and in the intelligence, wants and desires of the people, both

urban and suburban, practices will fit themselves, in time, into their surroundings, provided a few of the economical and scientific principles of fertility are clearly understood.

The by-products of the stable and farm may be applied to the land for one or more of the following purposes: as a winter cover, as a mulch, to improve physical conditions, to increase humus, to promote nitrification, and to supply food to growing plants. Moderately rotted manures are best applied in late summer and early fall, on the surface, and as soon as the ground is plowed. They should then be incorporated with the surface soil by the use of the harrow or cultivator, preparatory to planting to wheat, rye and like crops; or they may be spread upon the meadows and pastures. This presupposes that the manures of the previous winter have been piled or stored and partially rotted. Usually, it is found advisable to draw and apply a part of the manures as produced, or after they have been stored but a few days or a few weeks at most. In all such cases, they should be applied to the land upon which plants are growing; and since the entire farm should be covered with plants during the winter, the manures may be applied to those fields where they are likely to produce the best results. The practice of planting cover crops in late summer and fall, in orchards which have received clean culture up to the middle of July, and after the oats, maize and other like crops have been removed, is highly beneficial.

In some parts of the country deep snows make it inadvisable to practice winter manuring; but whenever conditions will permit, early winter application of manure will be found to advance the spring work, and to give much better results on grass and maize lands than late winter and spring manuring do. In the spring the fields are usually soft, and work is pressing; if, then, suitable provision is made for storing the by-products of the stables for the last two or three months before the animals go to pasture, some manure will be at hand for fall distribution, when the work of the farm is less pressing.

Whenever a systematic rotation can be carried out, and where maize, wheat and rye thrive, the manures of the last half of the winter may be stored and applied to the wheat ground, and those of the first part of the winter to the ground intended for maize. Climate, crops and practices vary so much that no rule can be laid down which will be applicable to all cases; this makes it necessary for every farmer to know many methods, that he may select the ones suited to his conditions.

If manures are applied freely to orchards, especially young ones, and to such crops as oats and barley, they may stimulate the vegetative system of the plants at the expense of fruitfulness, and result in positive damage; while such forage crops as the millets, maize, blue-grass and timothy, are seldom injured, but usually benefited by such applications. The annual growth of the trees, and the color and texture of leaf and young shoots, seldom fail to give

unmistakable signs of the presence of too much or too little nitrogen.

Manures are frequently wasted by being applied too liberally. It is not economical, except for special crops under special conditions, to apply from 20 to 40 two-horse loads or tons per acre at one time. The following is a brief extract from a letter received not long since:

"I have an acre of heavy soil manured with 100 two-horse loads of barnyard manure from horses, cows and hogs. It was plowed under, the ground fined, and another hundred loads applied, and the ground fined deeper than before. Then 75 bushels of slaked lime were harrowed in. The land was planted to potatoes." Later, the same correspondent writes: "The season was very dry, and I secured but 225 bushels of potatoes on the acre."

Supposing, now, that each load weighed one ton, and that the manure was of fairly good quality, that is, .6 per cent nitrogen, .3 per cent phosphoric acid and .45 per cent potash, it would have contained the following quantities of potential plant-food:

		400 bus. potatoes exclusive of vines require	225 bus. potatoes require	5 tons of manure would furnish potentially
Nitrogen...	240 lbs.	50 lbs.	28.1 lbs.	60 lbs.
Phos. acid.	120 "	17 "	9.5 "	30 "
Potash	180 "	70 "	39.3 "	45 "

What percentage of the potential nourishment contained in the manures plants can secure is not known, and it is unsafe to even assume any given

quantity, though some writers have thought it probable that under good conditions one-half might be recovered the first year. Be that as it may, the tables show conclusively that the amounts of the

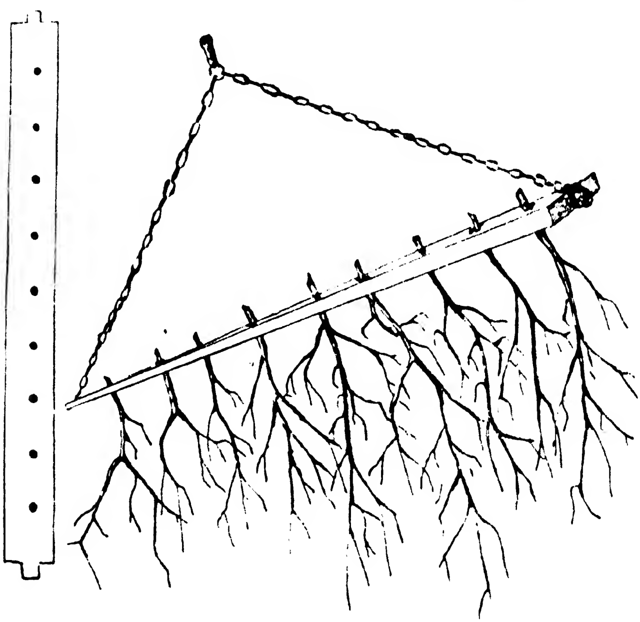

Fig. 35. Brush manure-spreader.

three valued elements supplied by the liberal manuring were so much in excess of the wants of the plants as to have been wasteful.

Liberal applications of coarse manures in the winter on clayey lands, especially those covered with grass, tend to keep them wet and cold until late in

the spring, which is seriously detrimental if the land is intended for maize, oats or barley. Nor are coarse, unrotted manures suitable for sandy land, unless the chief object is to form mulch or winter covering for the soil.

Unrotted manures, when spread from the wagon or sleigh in the winter, are not likely to be distributed evenly, and therefore some attention should be paid to redistributing them in the spring, before they become dry. On grass land this work may be done rapidly and well by means of a simple tool shown in the accompanying cut (Fig. 35, page 211). It may also be used to advantage on pastures, in the spring, to distribute the previous year's droppings of the animals which, if left undisturbed, cause rank bunches of grass, which are refused by the grazing animals. The implement is made of an oak plank one foot wide, pierced with suitable two-inch holes, into which is fastened heavy brush.

Manures should be fairly well rotted before being applied to sandy soils, or they increase the porosity of the land. Liberal applications of coarse, dryish manures plowed under may, if the weather is dry and remains so, do serious temporary damage. The more evenly manures are distributed the more efficiently they will act, but it requires no little skill and labor to perform the work in the best manner by hand. Two-horse manure-spreaders handle many kinds of manure in a most satisfactory manner under favorable conditions, but the conditions are so often unfavorable that they are not likely to come

into universal use. That the reader may not be distracted by the details of this subject, some of which must fail to meet his case, a few general though not universal rules, expressed in a few words, are given, the substance of some of which have already been stated.

Distribute manures in fall and early winter, thinly and evenly on or near the surface where plants are growing or will soon appear. Light and frequent applications are better than infrequent, liberal ones. A moderate increased production of many fields from year to year is better than a great increase on a single field for a few years. Barn manures are most economically used if associated with cover and green crops, improved tillage, and in many cases in conjunction with light applications of lime, potash and phosphoric acid, and in some cases with nitrogen, salt and gypsum.

CHAPTER X.

NITROGEN AND NITRIFICATION.

If a field of wheat, barley or maize is inspected before it approaches maturity, and especially when the plants are but a few inches high, it will be noticed that the foliage in some portions of the field is not only more luxuriant, but of a much darker green than that in other portions. These dark green places may be grouped together in small areas not larger than a foot in diameter, or they may occupy large areas, and in some cases the entire field may have a dark color. This denotes that the plants are abundantly supplied with nitrogen, and have at least a moderate supply of phosphoric acid and potash.

When the physical condition of the soil has been made superior by tillage, and suitable moisture is present, the plants are, under ordinary conditions, able to secure sufficient nitrogen for normal growth, although the soil may carry comparatively little nitrogen or nitrogenous compounds. Plants may suffer for want of nitrogen, although there is an abundance of it, in a potential form, in the soil. It is only in rare cases that the land does not contain enough potential nitrogen which could be made available profitably by intensified tillage, and most productive

soils carry potential nitrogen sufficient for from fifty to two hundred average crops of the cereals.

The first effort should be to determine whether it is best to hasten nitrification by extra tillage and aëration, or if it is more desirable to withhold the extra tillage and add purchased nitrogenous compounds. On light soils, tillage may be carried so far as to deplete the land of its humus, and lessen its moisture-holding capacity. Extra tillage presupposes that suitable measures will be taken to supply the soil with organic material by means of manures or plants, sufficient to keep the soil filled with humus and in a congenial physical condition. In some cases, it may be advisable to depend in part on purchased nitrogen, rather than to call upon the land for the entire supply needed, as in the latter case what is gained by extra tillage may be offset by the depletion of soil humus. Just how much reserve potential nitrogen should be carried, and how much humus, and how much should be brought from outside sources, can be determined only by the most careful experimentation and observation.

In promoting nitrification by tillage, the mineral constituents of the soil are also rendered more available. Here, again, is met the business or financial side of this problem; but it may be said that all plants are so markedly benefited by superior soil conditions that excellent physical conditions should be secured, even if the oxidation of the humus is carried farther than is desirable. Under ordinary conditions, tenacious soils are seldom seriously depleted

of their organic material by extra tillage, but when one crop follows another without any humus-producing crop intervening, especially in warm climates, meager production may be due quite as much to the lack of humus as to lack of available plant-food.

Whenever the physical condition of the land is superior, less potential plant-food in the soil is required for a given result than when the physical conditions are bad. How much may be taken out and how much reserve must be left in the soil, and yet maintain, and even increase, the most profitable production of the farm, is the problem which constantly recurs to the man who would secure the most satisfactory results, all things considered. This problem is followed by others,—how best to make the elements of the soil available, and how best to maintain the necessary reserve. It will be seen how complex agriculture becomes when an attempt is made to change nitrogenous compounds in the soil into available nitrogen with the view of removing it from the land, although at first we take no account of the chemical and biological changes which are constantly going on, and consider the question only from the farmer's standpoint.

The soil must contain, in addition to the necessary mineral constituents of plants, a suitable supply of available nitrogen, or the plants cannot make the necessary growth requisite for abundant fruitage. On the other hand, if the vegetative system of the plant is overfed by an excessive amount of nitrogen,

fruitage is reduced, and the plants are likely to be attacked by many enemies, such as rust and mildew, which they might in part or entirely resist if a less or normal amount of available nitrogen were present.

In general, it may be said that an abundant supply of phosphoric acid and potash, especially the former, tends to increase fruitfulness, hardiness and firmness of leaves and stems, while an abundance of nitrogen has a tendency to produce just the reverse conditions; and while the plant cannot be at its best without a suitable supply of nitrogen, the plants which are grown chiefly for their fruits may be easily injured by an amount only slightly exceeding a sufficiency.

At the Cornell Experiment Station, in recent experiments with wheat sown in drills twenty-four inches apart and given frequent tillage, the blades, stems and heads all showed that the plants were using an excess of nitrogen, which was made available to them by superior tillage and thin seeding. The wide intervals between the drills allowed the plants three times the feeding ground usually given. The period of maturing the grain was prolonged a full week, and the rust was far more abundant than on the leaves of plants growing in adjoining plats which had been drilled and treated in the usual manner. These observations were made on land of moderate fertility, from which one crop of maize and two of wheat had been taken in the previous three years, no fertilizers having been used on any of them.

When some crops, which are valued chiefly for their leaves and stems, are considered, there may be no danger from an abundant supply of available nitrogen, though it may be said that the quality of forage crops which have been highly stimulated by a superabundance of nitrogen is not as good as that of forage grown on land supplied with a less amount of nitrogen and a full or even liberal supply of phosphoric acid.

What has been said in regard to crops raised for fruit or for forage chiefly, does not always hold good when applied to the cultivation of maize, since this plant is not only able to grow on coarse and partially decayed farm manures without injury, but is benefited far more by added nitrogen than most plants are. The quantity and quality of the fruit and stalk of maize, if not planted too thickly, and if given suitable inter-tillage, appear to be benefited by not only an abundance of mineral plant-food, but of nitrogen as well.

It will be seen that a discussion or investigation of the subject of nitrogen and nitrification would be of little value unless the physical conditions of the soil and the available moisture which it contains are also considered. No matter how fully and cheaply the soil may be supplied with nitrogen and nitrogenous compounds, if it does not furnish a comfortable home for the plant, or if, for considerable periods, there is not enough moisture present to transport the plant-food into the plants, little benefit may be expected from the real or potential nourish-

ment carried in the land. Plants suffer oftener from lack of moisture than from lack of food.

To illustrate, the following results of investigations conducted in 1895–99 with potatoes at Cornell University Experiment Station are given. The land selected for the experiment was a gravelly soil underlaid by a porous subsoil through which the water readily passed. For twenty years preceding the experiment, a four-year rotation had been adopted,—clover or clover and timothy one year, mowed and pastured or mowed twice, lightly manured in the fall or early winter; maize one year; oats or barley without manure or other fertilizer one year; followed by winter wheat one year.

In 1893 a crop of clover was removed, and in 1894 a crop of maize was removed, after which the land was carefully divided into plats of one-twentieth of an acre each. Late in the fall of 1894 the land was plowed deeply, and about May 1, 1895, all plats were gang-plowed and thoroughly harrowed. May 3 and 4 potatoes were planted upon eight plats. The average yield from the eight plats was 353 bushels of potatoes per acre, or more than five times the average yield of potatoes in New York* (68.8 bushels). In 1896 the potato experiments were conducted upon plats adjoining and similar in character, though rather poorer, from which two crops of corn had been taken, one in 1894 and another in 1895. The potatoes were planted May 9, 1896, four plats (7, 8, 9 and 10) to

* According to the Eleventh Census of the United States, 1890.

Rural New-Yorker No. 2, and two plats (11 and 12) to Dutton. Plat 7 received fertilizer at the rate per acre of 200 pounds muriate of potash and 300 pounds of acid phosphate, while plat 8 received no fertilizer. Both plats were inter-tilled seven times, plat 7 yielding 310.5 bushels, and plat 8, 350.3 bushels per acre. Plat 9 was inter-tilled eleven times, and plat 12 seven times. They yielded respectively 338.1 bushels and 341.6 bushels per acre. Plats 10 and 11 were each inter-tilled three times. The former gave a yield of 280 bushels, and the latter 299.69 bushels per acre; or the two plats (9 and 12), with frequent tillage, gave an average yield of 339.85 bushels per acre, while the two plats (10 and 11), with infrequent tillage, gave an average of 289.83 bushels per acre.

In 1897 ten plats were devoted to experiments with potatoes. Of these ten plats, two (34 and 35) were inter-tilled eight times, and gave an average yield of 370 bushels per acre. Two plats (41 and 42) were inter-tilled seven times, and gave an average yield of 333 bushels per acre. Six plats (36, 37, 38, 39, 40 and 43) were inter-tilled five times, and yielded an average of 302 bushels per acre. The soil on these various plats was rather better on the plats which received the five cultures than on the plats which were cultivated eight times. All plats on which the above experiments were conducted in 1897 were plowed April 2 and 3, and thoroughly harrowed. In preparation and planting all plats were treated alike, and the widely varying results can only be ascribed to the better conditions provided by superior inter-tillage.

In 1898 tillage experiments with potatoes were conducted upon eleven plats, six of which received inter-tillage six times and five of which were inter-tilled three times. The average yield per acre from the six plats (21, 22, 26, 29, 30 and 32), which received six cultures, was 284.2 bushels per acre. The average from five plats (23, 24, 25, 27 and 28), which were cultivated three times, was 302 bushels per acre. While the increased tillage does not show the marked results upon the plats this year as in former years, the average of all plats is still well above the average yield for the state. A severe drought, preceded and followed by excessive rains, no doubt considerably reduced the yield. The plats which received three cultures were upon rather better soil than were the plats receiving six cultures. At one time during growth the moisture contained in the surface six inches of soil was reduced to 4 per cent. It is probable that where three cultures were given all the plant-food was liberated that could be brought into solution by the moisture present.

The most important lesson taught by this series of experiments is not the comparative yield of one plat with another, but the uniformly high yield from all plats. When it is considered that no fertilizer has been applied, except in one case, and that the land has been heavily cropped year after year, the importance of thorough preparation for the crop is emphasized. All the plats were deeply plowed from two to three times each year, and given the most thorough preparation before planting. Plowing was done early

in the spring before the stores of soil moisture had become disseminated by evaporation, the rainfall was quickly absorbed, and the inter-tillage kept the surface mulch renewed, and thus largely prevented loss by evaporation, and the plant-food which was made available was brought into solution and thus rendered of use to the growing plants. For detailed report and summarized tables, see Bulletin 156, Cornell University Agricultural Experiment Station, December, 1898, Third Report on Potato Culture.

Other equally striking experiments could be cited to show the marked effect produced by frequent and superior tillage in securing available nitrogen and in conserving moisture, but those given will suffice to call attention to the means which may be successfully used to furnish nitrogen and other necessary plant-food, and moisture, continuously to the growing plant. True, frequent inter-tillage benefits potatoes more than most other plants, since the earth-mulch, in addition to the beneficial effects already noted, serves to keep the soil cool, a condition which is highly beneficial to the potato in most localities. This earth-mulch was kept up until late in the season, and seemed to be quite as beneficial in the late as in the early part of the season, although it was not so perfect, since the cultivators had to be narrowed up, that the partly grown tubers might not be disturbed.

From these and other similar experiments, we are irresistibly led to the conclusion that the meager

crops so universally secured are usually not due so much to a lack of rainfall and potential nitrogen and other elements of plant growth in the soil, as to lack of ability or knowledge to make them available. Here, again, we arrive at the point where a choice must be made between utilizing the plant-food and moisture already in the soil, or securing the one by purchase and the other by expensive irrigation.

The discussion of the subject from the stand-point of the observant farmer, who would utilize in the best manner possible the latent wealth of the soil, naturally prepares the way for considering the plant's need of nitrogen, and the best means to secure the highest results by the utilization of the complex forces which, if understood, may materially assist in making a wise use of the land, while leaving it unimpaired for future generations.

The foregoing investigations show the need of testing the soil to determine if it will respond quickly and profitably to superior tillage, or if it may be necessary to add nitrogenous compounds, or to hasten nitrification by the application of lime, or by other means besides tillage. They also serve to emphasize the full meaning of the word manure, which is derived from the French word *manœuvrer*,—"to work by hand." *Manœuvrer* might be translated into modern thought by the single word tillage.

The need of nitrogen in the soil is succinctly set forth by Storer:* "Long-continued observation

* Agriculture, I. 292, 313.

and many experiments have proved that, beside the inorganic or ash ingredients of plants, there must always be some source of nitrogen in the soil, in order that a crop may attain any considerable development. The growth of forests and of all wild plants is really no exception to the rule. It is certain that there must be nitrogen in some shape in the soil, if there is to be abundant vegetation, and it is precisely in the case of wild plants that the influence of nitrates is on the whole most strongly marked. The nitrates, like other easily assimilable nitrogenized compounds, promote to a marked degree the growth of the leafy part of the plant, and the leaves of plants thus fed are characterized by a peculiarly intense green color."

"But let him [the farmer] do his best, he can never accumulate a very large proportion of nitrates in his field, for the soil has little or no power permanently to retain these substances. Every rainfall dissolves the nitrates which have formed in the upper layers of the soil, and carries them down into or towards the lower layers, and in case the rain should happen to be abundant and long-continued it may even wash the nitrates utterly out of the soil. The double silicates, which serve so well to arrest potash and ammonia, have no power to stop the waste of nitric acid."

One manurial ingredient can hardly be said to be of more importance than another, but one may assume more importance than another because of the greater expense or difficulty in securing it, or because

a slightly insufficient supply may more seriously affect production than when some other ingredient is insufficiently supplied to the same extent.

As has been previously stated, plants, like animals, tend to adapt themselves to the conditions under which they are placed, and so long as these conditions do not depart too widely from the normal, little or no harm occurs. A variety of wheat not infrequently gives virtually the same yield per acre when raised on soils widely different as to their character and composition. Of two plats of grain of the same variety, one may give much more straw than the other while the yield of grain is virtually alike, and the question is raised, had one too little nitrogen, or had one too much?

If the grains grown from various plats, differently fertilized, and which give virtually the same yield, be analyzed, it will be found that they differ materially as to the proportion of their constituents. It would, then, appear that a knowledge of the composition of the soil and plant does not solve the difficult problem of feeding plants, though such knowledge is likely to be of great advantage. Here, again, we are sent to the field with a long list of questions which can only be answered, if at all, in the presence of the growing plant. It must be fully realized, too, that the learner is in the presence, not of one force, but of many, which may act and react upon each other in complex and mysterious ways. An organized, living thing is to be studied, a flexible plant, subject, within certain limits, to

marked variations, in a single generation, and which may be increased and in time become fixed.

One leguminous crop in a four or five-year rotation, coupled with nitrogen-producing cover crops, can be made to furnish nearly all the nitrogen needed by the other crops in the rotation. Add to this the nitrogen contained in the excrements of domestic animals, that stored in the soil, and that brought to the land from natural sources, and the supply from these sources may be made equal to the demand, except for a few special crops.

Long experience in the management and tillage of widely separated farms, leads to the conclusion that under wise management a full supply of nitrogen for the ordinary fruits and grains, for lands which are now fairly productive, can be supplied from home resources in the greater part of the United States. Wherever land is reasonably cheap and the legumes flourish, and the climate is adapted to the rearing of domestic animals, the farmer is unwise who purchases nitrogen at from 12 to 20 cents per pound, instead of securing it from inexpensive home resources.

It is not difficult to make provision for keeping the soil fully supplied with potential nitrogen and humus, as the aid of a large variety of plants suited to varied condition can be secured in most localities. Some can withstand the severest winter; others are able to flourish in hot and even semi-arid districts, and may be used in part or wholly as humus and nitrogen producers. As soon as one

class of plants has fruited, and even before, other plants may be started, thereby keeping the land constantly employed in furnishing, through the plant, the desired nitrogenous compounds and humus. Add to these sources the farm manures, and the question of a supply of nitrogen is usually solved, provided, always, that skill is used in conserving it and in making it available. It is one thing to have the means at hand for securing a full supply of nitrogen, and quite another to know how to wisely use them; or, in other words, how most wisely to make use of plant, animal and soil to secure this high-priced and necessary element.

Plants are unable to live on the product of preceding plants until the organized matter of these preceding plants has been broken down and resolved into original compounds. Scientific farming may be said to consist in part in filling the soil with cheap and refuse potential plant-food, and in taking it out of the soil as finished products so skilfully that the supply is kept equal to the demand, and this with profit to the farmer and benefit to the land. It is one thing to put potential plant-food into the soil, and quite another to get it out profitably. There are various means used to secure the desired results, amongst which tillage has been already mentioned, but dependence should not be placed on this alone.

The relation of lime to nitrification demands a word at this point. While lime has been used to some extent for many centuries to furnish plant-food

indirectly, and while many investigations have been conducted to discover the complex action of lime when applied to the land, and while something is positively known as to its action, so many contradictory results are reached that the farmer is impelled to test its action not only on his own farm, but on every field of it, in order to arrive at facts which are applicable to his own conditions; and this is not strange, for the soil is not one uniform mass, but is naturally extremely variable. Most of the earthy parts of the soil have been transported long distances by the action of ice and water, sifted, sorted and deposited under such a multitude of conditions as to preclude the possibility, in many cases, of its being similar, much less alike, over a single field of a few acres. Not infrequently a single acre contains soils which may be classified under three or four entirely distinct heads.

But, as has been said, some of the effects produced by liming land are well established. When mild lime is applied in moderate quantities it tends to promote nitrification, and to make available the dormant plant-food. It may promote nitrification by improving the physical character of the soil, thereby making it more comfortable for the micro-organisms, or it may correct the acidity of the land, thereby promoting the multiplication of these organisms, or it may serve to supply a mineral element necessary to their well being, or it may, through its varied actions, arrest the development of denitrifying organisms. Neither the farmer nor

the biologist can tell, usually, whether only one or all of these beneficial effects have been produced, but they may know that benefits to a greater or less extent have or have not been received, by observing the plant and its fruit.

While a moderate application of lime usually promotes nitrification, a too liberal application may retard it. Aikman* states the case clearly when he says: "The action of lime on nitrogenous organic matter is of a very striking kind, and is by no means very clearly understood. As we have pointed out, it sometimes acts as an antiseptic or preservative; and this antiseptic or preservative action has been explained on the assumption that insoluble albuminates of lime are formed. Its action in such industries as calico printing, where it has been used along with casein for fixing coloring matter; or, in sugar refining, where it is used for clarifying the sugar by precipitating the albuminous matter in solution in the saccharine liquor; or, lastly, in purifying sewage,—has been cited in support of this theory. While, however, there may be circumstances in which lime, especially in its caustic form, acts as an antiseptic, its general tendency is to promote these fermentative changes, such as nitrification, so important to plant-life."

Gypsum is known to have the power of fixing ammonia (which is one part nitrogen and three parts hydrogen), and to hasten nitrification, and may be used in many cases to great advantage in both

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* Manures and Manuring, 460.

stable and field. The gypsum is sold without a guaranteed analysis, and too frequently it is little, if any, better than fine, dry, rich earth as an ammonia-fixer or a promoter of nitrification. It is, therefore, the part of wisdom to purchase sparingly until the purity and fineness of the product is known, or until there is certain knowledge that the benefits derived from the use of gypsum exceed in value its cost.

Nitrification is promoted either by long or short fallows conducted during the warmer months, but if a superabundance of rain falls upon the land before growing plants have made use of the nitrogen rendered available by tillage, serious loss may occur. This leads to the conclusion that fallow lands, and those which have received frequent tillage while producing a summer inter-tilled crop, should be fully occupied by plants before the fall or winter rains occur. Moderate rains may serve to carry the available nitrogen downward, but it tends to rise to or near the surface as soon as capillary action is restored. But if the water leaches through or passes off the land rich in soluble nitrogenous compounds, serious loss may occur.

While fewer nitrogen-producing plants are raised in the south than in the north, nitrification is far more active in the southern than in the northern states. These conditions indicate that the northern farmer should lay stress on hastening nitrification by increasing the temperature of the soil by drainage and tillage, while the southern farmer should cover

all his cultivated land with leguminous plants after the regular crops have been laid by or removed.

Since crimson clover is found to thrive all through the southern country, it would seem that a more general use might be made of it to great advantage. The first requisite to success is a suitable seed-bed. High ridge tillage, so universally in vogue in both maize and cotton fields, might be somewhat modified, especially in the case of maize, and somewhat more level inter-tillage given. After the summer tillage has been completed, a fine seed-bed could be prepared between the rows without destroying the ridges, by the use of a one-horse cultivator provided with many smallish teeth, passed over each space once before and once after the seeds are sown. In a similar way, all oat stubbles could be prepared and seeded, as well as orchard and other open lands. On these otherwise unoccupied spaces crimson clover could be used as a cover crop wherever it flourishes. Should the practice of using crimson clover as a catch or cover crop be associated with a more general cultivation of the cow pea, the problem of a supply of nitrogen for tilled lands would be practically solved for the south.

In most of the southern states a warm summer and fall, in which nitrification is extremely active, is followed by superabundant rains, which wash out the nitrogen liberated during the warm weather, and in some cases cause such degradation of the soil as to destroy its usefulness for tillage purposes. By covering the land with living plants, this degradation of

the soil might be prevented and the nitrogen largely conserved.

Beneficial results are frequently not secured by applications of nitrogen and other forms of plant-food, for one or both of two reasons. The breeding of the plant may be such that it can not make use of more food than the soil naturally supplies, or the soil may be so imperfectly fitted that the plant, no matter how high-bred, can not secure it.

Moisture plays an important part not only in the growth and fruitage of plants, but also in changing nitrogenous compounds into nitrates. Happily, the means used to conserve moisture and secure nitrogen may, at the same time, be made to increase or reduce the temperature and to secure superior physical texture of the soil.

Briefly, then, the living plant and the implements of tillage, intelligently used, furnish the means for changing dormant plant-food into that which is available, for conserving moisture, for promoting nitrification while adding and conserving nitrogen, for making the conditions comfortable for the crops, and for accomplishing these and other results in the simplest, cheapest and most satisfactory manner.

PREVENTION OF LOSS OF NITROGEN IN STABLE MANURES.

So much has been said concerning the absorption of nitrogen, or the retarding of nitrogen-loss, in manures, by means of various coverings and chemicals,

that a somewhat full abstract is here given of a recent German discussion of the subject.

In a recent article by H. Immendorff on the conservation of the nitrogen of stable manure,* the subject is introduced by stating that of the substances in manure which are to be saved, it is agreed that the nitrogen is of first importance and the organic matter next. As to the method of conservation—chemical or mechanical—much difference of opinion exists. This the author considers to be due to incorrect knowledge of the sequence of the events to be controlled, and to the insufficient separation of work of fundamental importance upon the subject from work of minor importance. It is of prime importance to know when and where, in the ordinary farm operations, losses occur, and what course of events causes them.

The dissipation of free nitrogen has been held by some to be the cause of the loss of value in manure. Exact experiments to determine this loss showed this element escaping (in the absence of nitrous or nitric acid) only when comparatively large quantities of air had access to the fermenting masses. This condition lasts at the most but 20 days in ordinary farm practice. Experiments by the author with bone, horn, flesh and blood meal without admixture of earth, and with much air accessible, showed as high as 60 per cent loss of the nitrogen contained in the original material in the form of ammonia; and the loss of free nitrogen was undeterminable generally,

*Journal für Landwirtschaft, vol. xlii. 1894. Translated by G. N. Lauman.

and in the case of greatest loss amounted to 6.2 per cent for a time of 121 days, giving for 20 days a loss of a fraction over 1 per cent.

With the addition of soil or soil extract to these materials, the conditions for the development of free nitrogen were much more favorable. In one experiment, showing the highest loss of free nitrogen, the soil was saturated with ammonium sulfate ($[NH_4]_2SO_4$) and then there escaped as free nitrogen, in 113 days, 20.6 per cent of the nitrogen in the original substance. This, calculated for 20 days, gives a loss of 3.8 per cent. Other experimenters have reached similar results, and Immendorff concludes that "the elementary nitrogen set free in the processes of fermentation and decomposition does not account for the great loss of nitrogen occurring in the manure from the moment of production to the time of deposition on the field."

In the foregoing, it has not been considered that in the presence of nitrous or nitric acid the losses of free nitrogen may become considerable. In normal, fresh manure, there are neither nitrates nor nitrites, and the first fermentations which take place are those in which large quantities of hydrogen-containing products, and even free hydrogen, are produced. It has, however, never been observed that during the most energetic formation of ammonia the nitrifying organisms develop any greater activity. In the stable, therefore, it will seldom or never happen that nitric acid will appear in such quantities as to cause serious trouble. On the manure pile, only

the surface offers an opportunity for the formation of the oxids of nitrogen, and here it may be of importance to check this tendency by good packing and covering.

From all the foregoing and other data which the author discusses, he concludes as follows: (1) "The chief cause for the loss of combined nitrogen which manure undergoes in the ordinary course of handling is to be sought in the escaping ammonia;" and (2) That "the formation of free nitrogen is, in a very subordinate measure, another cause."

Where and when are the greatest losses of nitrogen encountered? To this question the experiments of Müntz and Girard* give rather satisfactory answers. The great loss of nitrogen is found in the ammonia escaping during the very active fermentation beginning immediately after evacuation. Laboratory tests with the solid and liquid excrements separately, show that in the liquid excrements the ammonia fermentation is accomplished with great intensity, and all of the nitrogen changes to ammonia. The solid excrements, however, allow only small quantities of ammonia to be formed. As the greater quantity of the nitrogen in excrements is found in the liquid portion, the great loss of nitrogen in ammonia fermentation is explained; and, furthermore, the experiments show that at rather low temperatures, and also with the exclusion of all ventilation, the escaping ammonia may be considerable. In the stable, the conditions for ammonia fermentations

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* Annales Agronomiques, 1893, xix, No. 1, p. 5.

are more favorable than the conditions of these experiments were. On the manure pile, the conditions are less favorable to this development of ammonia fermentation, especially with good packing and sufficient moisture, when only the top layers are involved.

On the top of the manure pile, however, reactions take place which bring about the escape of free nitrogren. Here is where the process of nitrification begins, and, under certain conditions, develops great strength. Holdefleiss calculates the loss of nitrogen from the manure produced by cattle, in one year, to be 16.8 kilograms (36.9 pounds), and found that 23.4 per cent of the total nitrogen in the manure, when placed on the manure pile, had escaped.

How can the losses in the stable and on the manure pile be reduced to a minimum? The means which the author discusses are both mechanical and chemical, and these now follow:

Straw.—In an experiment with sheep bedded with a very large amount of straw, Müntz and Girard found that but 40 per cent of the nitrogen taken in as food was lost, while without straw the loss was 59 per cent. When but an ordinary amount of straw was used, the loss was 50.2 per cent. Straw is thus seen to have a certain although not very marked influence in the conservation of nitrogen.

Muck was compared with straw in an experiment with horses. The former showed a loss of 44.087 kilograms (96.991 pounds) of nitrogen, while the

latter showed a loss of 58.043 kilograms (127.694 pounds).

Earth.—With a sandy earth, properly prepared (dried in the air and passed through a 1.5 cm. [.59 inches] mesh), the experiment was made with sheep and compared with the results with straw. It was found that with earth the loss of nitrogen taken in the food was 25.7 per cent, while that with straw (as before noted) was 50.2 per cent.

The comparative efficiency of such materials when tested for their power of mechanically absorbing volatile ammonium carbonate ($[NH_4]_2CO_3$) resulted per kilogram of substance as follows:

Garden soil	5.38 grams taken up.
Heath "	6.60 " " "
Moss muck	8.63 " " "
Peat mold	11.03 " " "

It is thus seen that the humus soils and moss preparations are of great importance.

In addition to these experiments, Müntz and Girard tested in the laboratory the efficiency of an earth covering over fresh manure as a preventive of ammonia losses. The experiment excluded all ventilation. Under glass was placed fresh cow and sheep manure, 3 kilograms (6.6 pounds) of each, and in each case one sample was covered 2 cm. (.78 inch) deep with earth, while the other was left uncovered. The ammonia developed during the four months of the experiment was fixed in standardized sulfuric acid. The uncovered cow manure showed that 142 milligrams (2.1868 grains) of ammonia had

escaped, while the uncovered sheep manure showed 1,642 milligrams (25.2868 grains). The covered cow manure showed that 10 milligrams (.154 grains) of ammonia had escaped, and the covered sheep manure showed 128 milligrams (1.9712 grains). This experiment shows how an insignificant covering of earth can prevent the loss of ammonia. Müntz and Girard advise the farmer not to sell his straw, and in lieu procure muck, etc., for use in the stable and on the manure pile, but to use the straw, and make judicious use of the powers of the other materials.

Lime.—The use of lime was found by Müntz and Girard to accelerate the ammonia fermentation.

Thomas slag.—Holdefleiss found that the use of Thomas slag had the same effect as the use of lime, due, in all probability, to the not insignificant quantity of lime in the slag.

Sulfate of iron (copperas).—Müntz and Girard found that on the addition of this sulfate of iron, a combination was formed, resulting finally in the production of ammonium sulfate ($[NH_4]_2SO_4$), a non-volatile product. It was not, however, mentioned by Müntz and Girard that the large quantity of iron freed in the production of this ammonium sulfate could bring about the insolubility of the phosphoric acid in the manure.

Gypsum (plaster).—This material acts in the manner of sulfate of iron in that it causes to be produced ammonium sulfate ($[NH_4]_2SO_4$) and calcium carbonate ($CaCO_3$). But these reactions are not

carried to the end. The calcium carbonate ($CaCO_3$) in turn changes the ammonium sulfate ($[NH_4]_2SO_4$). In all such cases where gypsum was used, all salts possible from the elements involved were produced, namely, calcium sulfate ($CaSO_4$), ammonium sulfate ($[NH_4]_2SO_4$), calcium carbonate ($CaCO_3$) and ammonium carbonate ($[NH_4]_2CO_3$). The last mentioned salt always retains its volatile nature, and when allowed to escape was continually formed.

Kainit (sodium and potassium chlorides).—Kainit is supposed by Müntz and Girard to have the same influence on ammonium carbonate ($[NH_4]_2CO_3$) as gypsum does, on account of the magnesium it contains. Immendorff does not agree with this, and thinks the ammonium and magnesium salts readily form double salts, by which a weakening of the tension of the ammonium carbonate ($[NH_4]_2CO_3$) sets in. The possibility of the fixation of some ammonium in the production of ammonium and magnesium phosphates is allowed by Müntz and Girard. One very important property of kainit is not mentioned by these authors. It is the property of this salt to retard fermentations, and, strewn in proper quantities in the stable, where the loss is greatest, it will allow but little fermentation.

Superphosphate.—This substance, containing small quantities of free phosphoric and sulfuric acids, acts directly on ammonia through these acids in fixing it, and indirectly through the gypsum it contains. This latter action has already been explained. In Germany the most valuable chemical conserving

materials are considered to be superphosphates, rich in free phosphoric acid, and kainit.

Experiments in the laboratory were conducted with three samples each of cow and sheep manures, the same amount in each case. To one sample nothing was added, to another sulfate of iron, and to the third gypsum. The six samples, placed in closed vessels, were allowed to ferment from May 27 to October 8, 1883, and the ammonia formed was fixed in standardized sulfuric acid and determined, with the following results:

	Cow manure, loss of nitrogen. grams.	Sheep manure, loss of nitrogen. grams.
With nothing	.142	1.642
" sulfate of iron (copperas)	.085	1.092
" " " lime (gypsum)	.052	.409

A second experiment was conducted under similar conditions:

	Escaped ammonia, in grams.				
	6 days.	12 days.	21 days.	31 days.	54 days.
200 c. cm. cow urine, nothing added	.121	.333	.661	.950	1.350
200 c. cm. cow urine, with 2 g. gypsun	.072	.165	.349	.576	.895

The experiment shows that gypsum has a conserving effect, but cannot by any means conserve all the ammonia. Air currents were not used in either experiment.

Experiments in the sheep stable were conducted with sulfate of iron in small quantities. Twenty young sheep were bedded during 21 days on 30 kilo-

grams (66 pounds) of straw, which from time to time was strewn with sulfate of iron. During the whole of the experiment, 6 kilograms (13.2 pounds) of sulfate of iron were used, or 15 grams (.52 ounces) per animal per day. The result showed a loss of 48.5 per cent of the nitrogen taken in with the food. In previous experiments, to determine the proportion of loss of nitrogen in the stable to that contained in the food, the losses were not greater than in this experiment, showing that the sulfate of iron in small quantity had not the power to reduce this loss.

The same kind of experiments were conducted with sheep, using gypsum. Twenty young sheep were used for 21 days, on 30 kilograms (66 pounds) of straw, and every 4 or 5 days gypsum was strewn about. The total gypsum used was 12 kilograms (26.4 pounds), or 30 grams (1.04 ounces) per animal per day. The result showed a loss of 46.1 per cent of the nitrogen taken in with the food. In a second experiment the gypsum was increased. Ten sheep were used for 21 days on 40 kilograms (88 pounds) of straw. One kilogram (2.2 pounds) of gypsum was used daily, or 100 grams (3.52 ounces) per animal per day. The result showed a loss of 33.9 per cent of the nitrogen taken in with the food. Previous experiments, with no covering material other than straw, showed a loss of 55.3 per cent of the nitrogen in the food. It is seen that the larger quantity of gypsum prevented much ammonia from escaping.

The cause of the slight effect of small quantities of these chemical nitrogen-conservers, and especially of the sulfate of iron, has been thoroughly set forth by Müntz and Girard. Fresh manures from herbivorous animals possess a very high alkalinity, due, in general, to the large quantities of double potassium carbonate in the urine and the rather large quantity of calcium carbonate in the solid excrements. This alkaline reaction of the excrements is one of the causes retarding the action of chemical conserving agents. It is to be regarded, say Müntz and Girard, that according to well known reactions, sulfate of iron, gypsum, kainit, superphosphates, etc., must neutralize the fixed bases, which are in the manure in the form of carbonates, before they are able to bind the ammonia. The alkalinity of various excrements was determined by the amount of sulfuric acid which one kilogram (2.2 pounds) of the excrements in question would neutralize, and resulted as follows:

	Grams.	Av. of determinations.
Horse manure (solid and liquid)	1.35	4
Cow and oxen manure (solid and liquid)	3.64	7
Sheep manure (solid and liquid)	4.29	4
Hog manure (solid and liquid)	2.02	2

In another experiment, comparing the alkalinity of the solid and liquid excrements separately, on the same basis as above, the following results were obtained:

	Urine, grams.	Dung,
Horse	3.4	seemingly neutral.
Cow	6.8	2.59
Sheep	14.26	1.88

Müntz and Girard consider that the property of sulfate of iron in holding ammonia is proportional to the amount of the sulfuric acid it contains, or about 25 per cent of its weight. They then calculated the following table:

Manure. (Weight of animal)	Amount of manure in lbs. produced in 1 year	Ave. loss of ammonia in stalls, in lbs.	Sulfate of iron to combine with ammonia, in lbs.	Sulfate of iron to neutralize alkalinity, in lbs.	Total sulfate of iron necessary, in lbs.
Horse (1,210 lbs.)….	22,400	28.38	324.28	121.44	445.72
Cow (1,320 lbs.)……	25,080	101.64	1,161.60	365.86	1,527.46
Sheep (99 lbs.) ……	1,760	15.18	173.36	30.14	203.50

The enormous quantities of sulfate of iron are the minima necessary to hold all the ammonia, and, in practice, still larger quantities would certainly be necessary to arrive at the desired results. The price of this sulfate of iron would be almost two-thirds of the value of the conserved nitrogen.

The authors think that the same results would be had with kainit. Both substances would, by the fact that the alkalinity of the manure is destroyed, hinder the rotting of the manure, and thus cause a lessening of its value.

With the data from their experiments, Müntz and Girard come to the conclusion in regard to the use of chemical nitrogen-conserving agents, that "on account of the presence of fixed bases, too large quantities of such agents must be used, so that the good to be derived from their action is in a large measure lost."

With superphosphate, Müntz and Girard did not experiment in this way, and Immendorff is of the

opinion that since much smaller quantities of this are necessary, at the present prices it may be used to advantage under certain conditions, either alone or with kainit or other potash salts, as these latter are supposed to retard ammoniacal fermentation.

From the foregoing discussion in Immendorff's paper, it is safe to conclude that, all things considered, nothing better than dry earth containing a large percentage of humus has yet been found for conserving nitrogen in the stable and in the manure heap. While gypsum is valuable for this purpose, there are many localities where it cannot be easily procured, and in any case, its first cost is considerable, while humus and earth are abundant on most farms, and can always be secured and stored for use at a nominal cost. It is gratifying to know that the farmer has always at hand the means of preventing largely the loss of nitrogen in barn manures, means which have heretofore been left almost entirely unused, although the value of the dry-earth closet as a sanitary agent is well known to tidy farmers.

EXPLANATION OF NITRIFICATION.*

Nitrogen in the form of nitrate is generally regarded as the best kind of nitrogen-food for plants. Nitrates are compounds of nitric acid with metals or bases, as potassium nitrate (KNO_3), sodium nitrate

* By George W. Cavanaugh, Assistant Chemist in the Cornell Experiment Station.

($NaNO_3$), calcium nitrate ($Ca[NO_3]_2$) and ammonium nitrate (NH_4NO_3). Plants obtain their nitric acid by absorbing (1) the nitrates that are already present in the soil; (2) those that are carried down to the soil from the air in rain and snow; (3) those that are applied artificially in fertilizers, and (4) those that are formed in the soil from the nitrogen of other substances. As is well known, all of the nitrogen that is applied to the soil for fertilizing purposes, especially in barn manures and green cover crops, is not in the form of nitrates. It may be either in the form of ammonia (NH_3), or of more complex organic compounds. It is very probable, however, that before it is taken up by the plant, the organic nitrogen is changed first into the form of ammonia (NH_3), and then into nitric acid (HNO_3). These changes all take place through the agency of micro-organisms or ferments, and that particular process in which the nitrogen of the ammonia is changed into nitric acid is called nitrification. This change is accomplished by the joint action of two separate organisms, one of which changes the nitrogen of ammonia into nitrous acid (HNO_2), while the other changes the nitrous acid into nitric acid (HNO_3). Perhaps a clearer idea may be obtained if nitrification be considered as a process somewhat comparable to the fermentation by yeast.* In the case of the yeast, part of the carbon of the sugar is liberated as carbonic acid gas, or carbon

*This comparison is given only to emphasize the fact to the general reader that nitrification is a biological process.

dioxid (CO_2), while the nitrifying organisms change the nitrogen of ammonia into nitric acid (HNO_3).

The conditions that are required for the development of nitrifying organisms are the presence of certain food constituents, heat, moisture, oxygen, and some base to neutralize the nitric acid as it is formed. It is also necessary that the soil be slightly alkaline, but too much alkali retards the process. The nitrifying organisms require certain substances as food, among which phosphoric acid is most important. It has been found that without phosphoric acid there can be no nitrification. This may be one of the reasons why phosphates show beneficial results when applied to some soils, as well as furnishing plant-food directly. The three conditions which exert a marked influence on nitrification, and which in agricultural practice are more or less intimately associated, are heat, air, and moisture. The process is most rapid during warm weather, in presence of sufficient air and moisture. Here, then, is one of the reasons why thorough tillage is essential. The loosening and pulverizing of the soil allows the admission of the necessary oxygen, and regulates the supply of moisture. If the soil is very dry, or is flooded with water to the exclusion of air, nitrification is retarded, and may be permanently stopped. In this connection, it is interesting to note that in pasture lands, which receive no tillage, and, consequently, are more impervious to air than cultivated fields, nitrites, or compounds of nitrous acid, are more abundant than nitrates.

The final product of nitrification is nitric acid. But the nitrifying organisms cannot develop in the presence of a free acid; hence the benefit of liming sour soils. The lime corrects the sourness of the soil by neutralizing the free acid, and then if the other conditions of heat, oxygen, moisture and food are favorable, nitrification may proceed. There must be an excess of lime applied over and above the amount necessary to correct the acidity of the soil, to neutralize the nitric acid as it is formed. When the lime combines with nitric acid, the reaction can be expressed by the following equation:

$$CaCO_3 + 2HNO_3 = Ca(NO_3)_2 + CO_2 + H_2O.$$

One part of calcium carbonate ($CaCO_3$) reacts with two parts of nitric acid (HNO_3) to form one part of calcium nitrate ($Ca[NO_3]_2$), one part of carbon dioxid (CO_2) and one part of water (H_2O). In this equation mild lime (calcium carbonate, $CaCO_3$) is used, because this is the form of lime most favorable for promoting nitrification. When caustic or hydrated lime ($Ca[OH]_2$)—that is, water-slaked lime—is applied to soils, it may act energetically, tending to decompose and render available the insoluble compounds of potash. True, the caustic lime may have at first a retarding effect on nitrification by rendering the soil too alkaline, but exposure to the atmosphere soon converts it into mild or air-slaked lime ($CaCO_3$), when it is in its best form for promoting nitrification.

Whenever the soil is in a condition unfavorable to nitrification, there is danger that not only may nitrates not be formed, but that there will be a loss of nitrogen from those nitrates that may be present. This loss is due to a process known as denitrification, which is also dependent on micro-organisms. The denitrifying organisms flourish under one condition which is directly opposed to the corresponding condition favoring nitrification,—namely, the absence of oxygen. Under that condition the nitrates may be reduced or changed back to nitrites, and the nitrites are often further reduced till they lose their nitrogen by having it pass off into the air as gaseous nitrogen.

Denitrification may take place, therefore, in water-logged soils and in the inner parts of manure piles,* where air is measurably excluded.

The organisms found in the tubercles on the roots of clovers and other legumes are not the organisms that produce nitric acid. Their office is to fix or seize upon the free nitrogen of the air.

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*This subject is discussed from the horticultural standpoint in Bailey's Forcing-Book, p. 62.

CHAPTER XI.

THE PHOSPHORIC ACID AND POTASH SUPPLY.

THE amounts and availability of these two mineral elements of plant life vary greatly in soils. It is evident that the lands from which crops have been harvested for a series of years, and those which have been devoted to pasturage, must contain less of these minerals than they did when first reclaimed from a state of nature, and this is true even when the most painstaking effort has been made to return to the land the refuse material and manures resulting from crops and animals, for it would be impossible to return all that had been removed, since there would be no object in harvesting crops or keeping animals unless their edible or commercial parts were used or sold. Therefore, no matter how economically the native supply of these elements has been conserved, or how skilfully the elements have been made gradually available, the time must come, sooner or later, when the native supply will be so diminished as to require additions from outside sources, if full crops are to be maintained.

HUSBANDING THE MINERAL PLANT-FOODS.

The problem which should first arrest the attention of the husbandman is, how much phosphoric

acid and potash must be carried in the soil, and how much may be taken out without reducing the reserve below the profitable standard. And it requires no little skill to solve this problem. This is followed by a question equally difficult: How best to make available, and when once available, how to capture and hold the mineral matter which it is proposed to remove. Shall drain tiles, or plants which are able to thrive on "tough" food and to transform it into that which is "tender," or better implements of tillage, one or all, be used to force the harvests from the "face-sweating, stubborn glebe?"

How far shall we go in our endeavors to make the dormant minerals soluble? If they are made soluble by tillage and other means, they pass but a short way into the soil before they unite with bases, and again become insoluble. Shall the effort be to proceed only so far with tillage as will give the plant opportunity to set free its own mineral food by the action of its roots; that is, make the material in the soil available? The question is not answered when we dodge behind the word "available," for however available the food may be, if there are not suitable roots and rootlets, or enough of them, to take advantage of the food prepared, or if the rootlets are not made comfortable, the full power of the soil cannot enter into the plant.

Most soils carry vast amounts of phosphoric acid and potash (see Tables I. and II.), much of which, under careless or even ordinary tillage, appear to be nearly or entirely useless. If the tables in the last

Census Report are scanned, it will be seen that either the soil in the United States is carrying but little available plant-food, or that the skill has not been acquired to make the stores available. An inspection of the fields, and also of the tables which give the numerous analyses of soils made in this country, compel the conclusion that the meager average yield of crops is not due, in a majority of cases, to a lack of mineral constituents in the soil, nor to any unusual combination with bases which might cause them to be so firmly held as to make their liberation extremely difficult.

Most of the land in the United States has been under cultivation less than one hundred years,—extended areas less than fifty years; yet the cultivation of some of the more exacting crops, as wheat, has been abandoned in many localities because the available supply of plant-food in the soil under present methods of tillage is less than is required for a profitable yield. In some localities, wheat growing has been abandoned because the production of garden crops or milk and fruit is found to be more remunerative than the growing of cereals. The average production per acre of some of the crops substituted for wheat is so small,—potatoes for instance,—(the average yield in New York, 1889, was 68.8 bushels per acre), that it is conclusive evidence that the land, after less than a century's use, is seriously depleted of its life-giving elements, or that villainous methods of tillage and plant protection have been and are in vogue. There is abundant

evidence to prove that the fault lies more largely with the tiller of the soil than with the soil itself.

For a supply of the mineral constituents of plants, both home and commercial sources are open. The home supply is found in the soil and the refuse material of the farm, which latter may be augmented by purchased animal-foods. Stress should first be laid on conserving the mineral elements which have once entered into organic substances, for such matter, having once entered into plant and animal life, is easily broken down and made available for succeeding life; or, in other words, mineral matter which has recently been made available and used by plants may be made re-available more easily than that which has never been used.

The next thought is to tickle the soil with tillage, and see if it will laugh with fatness; if it does not, apply something which will awaken it more effectually. If by the use of comparatively cheap substances, as lime and gypsum, the phosphoric acid and potash can be ousted and made available more cheaply than they can be bought for the land, then these cheap substances should be used, for they usually not only set free plant-food, but also improve the physical character of the soil, and sometimes serve as regulators of soil moisture.

As has already been stated, it is manifestly impossible for every farmer to have the soil of even a single field analyzed; much less can he have a chemical determination made of all the fields, or portions of fields, of the farm, and even could this

be accomplished, the difficult problem of productivity would be only partially solved. The difficulties met every day in every field can best be overcome by increasing the farmer's powers of observation, by developing his judgment and by supplying him with clear-cut scientific facts, that he may have a basis for drawing correct conclusions from what he observes. In farming, as in religion, salvation is worked out through personal effort, illumined by knowledge, and directed according to the laws or modes of action which govern the subject investigated.

Since phosphoric acid and potash leach out of good soils in only extremely small quantities, it would seem at first thought that the presence of a living plant would not be necessary to conserve them, as in the case of nitrogen; but if these minerals have been made available by tillage or by amendments to the land, and if they are not used, they tend to become unavailable again as time passes. True, while the natural forces are tending to lock up some of the mineral plant-food which has been made easily available, other forces may be liberating plant-food which before such action was unavailable. For instance, the natural forces are constantly active in breaking down rock, sand and organic matter, and they are equally active in conserving or locking up any of the mineral constituents which have been made soluble. Since plant roots set free or make soluble the available minerals, cover crops should be used extensively, not

only for covering and shading the land, but for their value in setting free the mineral constituents of the soil. Where practicable, tap-rooted plants should be used for this purpose, since they are not only as active in liberating plant-food as fibrous-rooted ones are, if not more so, but they also bring food from the subsoil to the surface, where the more exacting fibrous-rooted plants may use it. Tap-rooted plants also tend to improve the sub-drainage of tenacious soils, and to make them more friable by opening up channels for the passage of air and water downward and moisture upward, when their roots have decayed.

Lime may not only change the physical conditions of the soil for the better in several characteristic ways, but it may also act in such chemical ways as to make dormant phosphorus and potash available. Salt and some other substances may also act in similar ways. (See Chapter XIII.)

A quarter of a century since, gypsum was largely used in the central states with marked beneficial results. In later years its use has decreased, because there is less potash in the soil. Farmers have taken the potash from the soil, and have then blamed the gypsum, instead of taking themselves to task for not returning some of the potash.

The characteristic action of gypsum as a liberator of plant-food is briefly and clearly stated by Aikman.* "The true explanation of the action of gypsum is to be found in its effect on the

* Manures and Manuring, 463.

double silicates, which it decomposes, the potash being set free. Its action is similar to that of other lime compounds, only more characteristic. As a manure, therefore, its action is indirect, and its true function is to oust the potash from its compounds. Its peculiarly favorable action on clover is due to the fact that clover specially benefits by potash, and that adding gypsum practically amounts to adding potash. Of course, it should be borne in mind that the soil must contain potash compounds, if gypsum is to have its full effect. Now, however, that potash salts suitable for manuring purposes are abundant, it may well be doubted whether it is not better to apply potash directly. Further, it must be borne in mind that gypsum is applied to the soil whenever it receives a dressing of superphosphate of lime, as gypsum is one of the products formed by treating insoluble phosphate of lime with sulfuric acid."

He who utilizes, as conditions will permit, lime, gypsum, salt, plants, drains, manures and extra tillage, may still find that the land is not as fruitful as it should be, because of insufficient mineral matter. Unsatisfactory results may be, and in a large majority of cases are, due to a lack of full and continuous supply of moisture, and this being so, it would be manifestly unwise to purchase plant-food, when that already available is not fully utilized for lack of ample transportation facilities. In all cases, pains should be taken to discover just what is lacking,—moisture or plant-food. If the latter, and if an in-

telligent effort has been made to utilize the natural and home resoures, there should be no hesitation in purchasing freely to make up the deficiency. Paradoxical as it may appear, those farmers who make the best use of the home and natural supply of plant-food are the ones who purchase commercial fertilizers most freely and mostly profitably.

COMPARISON OF NATIVE SOILS WITH THOSE CULTIVATED FOR SEVERAL YEARS.

The following quotations are taken from investigations made by Harry Snyder, chemist of the Minnesota Agricultural Experiment Station, Bulletins 30 and 41. These publications are well worth a most careful perusal:

"The Red River Valley native soils," he writes, "contain from .35 to .40 of a per cent of nitrogen, while the soils that have been under continuous cultivation for twelve to fifteen years contain from .2 to .3 of a per cent."

Presumably the cultivated soils had been tilled without any intervening nitrogen or humus-producing crops. Allowing that an acre of soil, one foot deep, weighs 1,800 tons,* the native soil would contain from 12,600 to 14,400 pounds of nitrogen per

*The assumed weight of an acre of soil is slightly greater than the weights reported in the two bulletins above named (in a majority of cases), but is less in some cases. Most plants secure some of their food from greater depths than one foot; therefore, for the purposes of comparison and illustration, the assumed weight of an acre of soil one foot deep is sufficiently correct.

acre of native soil one foot deep, while the cultivated soil would contain from 7,200 to 10,800 pounds per acre. If the average amount of nitrogen in the native soils (13,500 pounds per acre), and the average in the soil after it had been cropped twelve to fifteen years (9,000 pounds per acre), are compared, it will be seen that the soil has lost 4,500 pounds of nitrogen, or more than one-third (possibly one-half) of the nitrogen which could well be made available.

The suicidal practice of robbing the richest of soils by continuous production of wheat, sold at from 50 to 60 cents a bushel, limits the occupancy of this land to forty-five years, unless radical changes are instituted. Through present need or present greed, the American is squandering his valuable landed estates as a dissolute son squanders his inheritance. Fifteen crops of wheat of twenty-five bushels per acre require 525 pounds of nitrogen, or one-eighth of the amount which the soil lost during the twelve or fifteen years of cropping. This soil has been so badly managed that it has lost outright nitrogen sufficient for 120 crops, each requiring as much nitrogen as a crop of twenty-five bushels of wheat per acre does. In addition to this, all of the 525 pounds of nitrogen carried off by the wheat was sold at the railway station, never to return. When the amount wasted on a single acre is multiplied by the acres of the vast fertile wheat plains of the west, the loss of nitrogen to our country is seen to be so great as to appall the

thoughtful man who looks forward to the generations who will want this element in the not distant future.

"In the uncultivated soils there is usually about 5 per cent of humus, while in the cultivated soils there is usually less than 3 per cent. The humus is very rich in nitrogen, the important building material out of which the gluten in wheat and grains is constructed; and when the humus decreases the nitrogen decreases as well, and is lost from the soil.

"The effects of the humus on the capacity of the soil to retain its water and withstand the evil effects of drought are marked; the native soils will retain about 20 per cent more water than the long cultivated soils, and will not dry out as readily during the droughty seasons as the older and long cultivated soils. Another important point: when the humus is taken out of the native soils, during the process of analysis, from .06 to .08 of a per cent of phosphoric acid is soluble and associated with it; while only about .02 of a per cent is in this form with the long cultivated soils. Phosphoric acid in this form is very valuable as plant-food. There is a good supply of phosphates in all of these soils, but we must keep up the supply of humus in order to keep the phosphates available.

"In the analyses reported, the average amount of potash is given as about one-half of 1 per cent. This is not the total potash that is in these soils; in fact there is about 1¾ of a per cent in all, but 1¼ per cent, or over two-thirds of the total, can-

not be counted upon for crop purposes, because it is combined with silica (sand) in the form of minute stony particles, that require the strongest chemicals and the highest heat that can be procured in the laboratory to decompose them."

It will thus be seen that the great value of humus resides not only in its increasing of the moisture-holding capacity of the land, but in its power of liberating phosphoric acid. While the land contains an unusual supply of potash, this material is present in such forms that the greater part of it cannot be made available to plants, at least not in the near future.

CHAPTER XII.

COMMERCIAL FERTILIZERS.

THE use of commercial fertilizers has increased so rapidly during the last thirty-five years that their manufacture, sale and value in agriculture have become of national importance. From small and crude beginnings prior to 1860, at which date there were but forty-seven small fertilizer establishments in the United States, with an output valued at $891,344, the establishments had increased, by 1889, to 390, and the value of the output to $39,180,844 at wholesale.*

STATISTICS OF FERTILIZERS.

	1860. Industry and wealth, eighth census.	1870. Industry and wealth, ninth census.	1870. Value of the fertilizers in those states which manufactured more than $500,000 worth.	
Establishments........	47	126	Penna.	$1,635,204
Hands employed.......	308	2,501	N. J...	661,659
Capital...............	$466,000	$4,395,948	Mass...	647,700
Wages	95,016	766,712	Md.....	632,352
Materials..............	590,816	3,808,025		
Products	891,344	5,815,118		

* United States Census Report, 1890. The tables set forth briefly the growth of the fertilizer industry by decades during the thirty years prior to 1890.

	1880. Statistics of manufact's tenth census, Vol. II.	1890. Manufactu'g industries, elev'th census, Part I.	Value of the fertilizers in those states which manufactured more than $500,000 worth. States.	1880.	1890.
Establ'hm'ts	364	390	Md.	$5,770,198	$6,208,025
Hands emp'd	8,598	10,158	N. Y.	5,150,312	3,498,291
Capital	$17,913,660	$40,594,168	S. C.	2,691,053	4,417,658
Wages	2,648,422	4,671,831	N. J.	2,423,805	4,319,088
Material.....	15,595,078	25,113,874	Mass....	2,164,680	1,910,920
Products....	23,650,795	39,180,844	Penna. ..	1,433,245	2,957,316
			Ind.	980,725	
			Ill.	729,400	924,758
			Del.	675,250	1,018,438
			Va.	624,300	2,475,638
			Ohio.....	531,540	1,287,101
			Ga.......		5,026,034
			N. C.....		994,135
			Ala......		765,000
			Mich		753,585

The American farmers have paid out for commercial fertilizers, during the last thirty-six years, more than eight hundred million dollars, an amount equal to the value of the entire wheat crop of the United States for the last three years. The question naturally arises, was this money, in part or as a whole, wisely and profitably invested? If this vast amount is expended for plant-food before the arable land has been under cultivation three-fourths of a century, on an average, and when, as yet, nineteen states and territories, embracing more than one-half of the land surface of the Union, use little or no commercial fertilizers, what sum will suffice for purchasing plant-food when all the arable land has been cropped for two or three hundred years? Will our nation

die in time, as many others have in the past, because the land will fail to produce sufficient varieties and quantities of first-class foods to keep the whole population on a highly civilized plane? The variety and quality of the foods used by a people will in time determine, more than any other one thing, the height of civilization or the depth of semi-barbarism which the nation will reach. When we consider the rise and fall of nations in the past, and look upon the abject poverty, the hunger and suffering, the lack of a competence and leisure, and the utter dearth of innocent luxuries which fall to the lot of more than one-half of the inhabitants of the Old World, we naturally seek for the cause or causes which have produced these conditions. The elements of food, clothing and a competence are found primarily in the soil; if these elements remain inert, or are depleted through ignorance or carelessness, no abiding prosperity can be expected.

Is this favored nation to follow in the footsteps of many others, and shall we look on with stoical indifference while the fertile valleys, the extended plains and the wood-clad foot-hills are slowly but surely being transformed into eroded, semi-barren and weed-covered wastes? Are the forty to sixty millions of dollars now paid out annually for commercial fertilizers, after less than seventy-five years' occupancy of the land, an indication of advancement or retrogression? How much of the fertilizer used is applied to badly tilled land which, under good tillage, would produce satisfactorily with-

out fertilizers? Has the expenditure of forty millions of dollars yearly for commercial fertilizers by some twenty states noticeably increased the average yield in these states, or only served to keep it from falling below the average of early years? In what direction does the road which the American farmer is now traveling lead,—to greater or less productivity of soil? Will the methods now pursued make it possible at the end of the twentieth century for every honest, temperate and industrious man or woman to earn each day enough to supply the necessities of life and a modest surplus,—conditions which may now be reached by nearly all able-bodied farmers in America? All these questions are worth thoughtful consideration, though no one may be able to answer them definitely.

It will be seen how far-reaching the subject of commercial fertilizers and continued productivity of the land becomes when viewed in the light of the past, and with regard to the welfare of the future of our country. It is not enough to say that by using a given amount of fertilizers on a given area there will be an increase of crop, or that such an application will be profitable. To treat the subject from this mole-like, immediate-profit point of view, is to lose sight of the real problem to be discussed and solved. The real question is, how to use the land most wisely, how most economically to produce high-classes of food for the eater, an extended variety of cheap food for the consumer while insuring a profit to the producer, and an increase in

the productivity of the land. We who have secured our farms from an over-kind government at a minimum of cost have no right to use the soil simply for the sustenance of the present generation, and hand it over to future generations with no thought of their welfare.

GENERAL REMARKS UPON THE USE OF COMMERCIAL FERTILIZERS.

The productivity of the land used for the growing of field crops cannot be indefinitely maintained without the application of some of the mineral elements of plant growth. To determine the period when it is best to substitute, in part, additional plant-food for additional tillage, is not simple, neither is it always easy to determine the amounts and kinds of plant-food which it is wisest to apply. The experience of every farmer who has grown a clover or other leguminous crop will lead him to the conclusion that the one high-priced element of plant-food, nitrogen, is the one that is most easily and cheaply procured. This fact simplifies the problem of maintaining productivity, as governed by one element, in many portions of the country.

Questioning the soil as to its mineral constituents would not be difficult, if a practicable method for cheaply determining the availability of the potash, phosphoric acid and lime, and their various combinations in the soil, had been discovered. Here, as in so many other instances, the chemist and the

farmer must join hands and work together, one with crucible and retort, the other with plow and plant. From now on the plow-share must be kept hot, and the farmer must be alert, that he may take advantage of every new discovery of the student.

From a few brands of natural and manufactured fertilizers, the number of mixtures has grown to bewildering proportions. The New York State Experiment Station (at Geneva, N. Y.) registered in 1896, up to November 20, 126 manufactories and 1,112 separate and distinct brands of fertilizers. It would be uncharitable to suppose that this multiplication of brands is intended to confuse the farmer, yet this is the result. If a suitable fee were required of the manufacturer for each brand of fertilizer sold in New York (see fourth column in Table LXXX.), it would not only tend to reduce the multiplication of them, but, if wisely expended, would produce a fund sufficient to guard the rights of the purchaser and the conscientious manufacturer. True, the fee, or the greater part of it, would eventually be paid by the user, but he would willingly bear such additional expense could he be assured that he received just what he paid for. Then, too, he has a right to a guarantee of the composition and weight of each sack or package, set forth in terms so plain that he will not be compelled to employ an interpreter to reveal the meaning of the terms used.

Abstracts of the laws for the regulation of the fertilizer trade in the various states are given below:

TABLE LXXX.—*Abstracts of fertili-*

No law.	Label must show name of manufacturer, place of manuf'ture, brand or trade-mark, guaranteed per cent of N. or equivalent NH_3, K_2O and P_2O_5.	Analysis fee is required for each ingredient claimed.	License or analysis fee for each brand sold.
Arizona.	Alabama.	Connecticut $10.00	Delaware .. $30.00
California.	Connecticut.	Maine, for P_2O_5 ..... 10.00	Illinois 20.00
Colorado.	Delaware.	N or K_2O. 5.00	Indiana 2.00
Idaho.	Florida.	Massachusetts...... 5.00	Kentucky.. 15.00
Iowa.	Georgia.	Rhode Island....... 6.00	Maryland. . 15.00
Kansas.	Illinois.	West Virginia...... 10.00	Michigan .. 20.00
Minnesota.	Indiana.		Mississippi 15.00
Montana.	Kentucky.		Missouri. .. 10.00
Nebraska.	Maine.		NewJersey. 15.00
Nevada.	Maryland.		Ohio 20.00
New Mexico.	Massachusetts.		Pennsylv'a. 10.00
North Dakota.	Michigan.		Virginia excess of 10 brands, ea. 10.00
Oklahoma.	Mississippi.		Wisconsin. 20.00 / 25.00 / 50.00
Oregon.	Missouri.		
South Dakota.	New Hampshire.		
Texas.	New Jersey.		
Utah.	New York.		
Washington.	North Carolina.		
Wyoming.	Ohio.		
	Pennsylvania.		
	Rhode Island.		
	South Carolina.		
	Tennessee.		
	Vermont.		
	Virginia.		
	West Virginia.		
	Wisconsin.		

zer laws of different states.

License fee for each manufacturer, to cover all brands.		A tax required for each ton sold.		Penalty for non-compliance with the fertilizer laws.	
New Hampshire	$50.00	Florida ...	$0.25	Alabama..........	$100.00 to 5 yrs. imprisonment.
Vermont...	100.00	Georgia...	10	Connecticut	$100.00 to $200.00
Virginia, 10 brands or less	100.00	North Carolina	25	Delaware	200.00 " 300.00
		South Carolina	25	Florida	500.00 " 1,000.00
		Tennessee	50	Georgia...........	Punished as misdemeanor.
				Illinois	$200.00 to $500.00
				Indiana...........	50.00 " 100.00
				Kentucky	100.00 " 500.00
				Maine	100.00 " 200.00
				Maryland	100.00 " 200.00
				Massachussetts ...	50.00 " 100.00
				Michigan	100.00 " 300.00
				Mississippi	Forfeiture and damages.
				Missouri..........	$100.00 to $200.00
				New Hampshire ..	500.00
				New Jersey.......	50.00 to 100.00
				New York	100.00
				North Carolina....	per bag, 10.00
				Ohio..............	200.00 to 500.00
				Pennsylvania	25.00 " 200.00
				Rhode Island	50.00 " 100.00
				South Carolina....	Not to exceed $1,000.00
				Tennessee	$50.00 to 100.00
				Vermont	50.00 " 100.00
				Virginia	1,000.00
				West Virginia.....	10.00 " 100.00
				Wisconsin	100.00 " 200.00

The question is frequently asked, Can the farmer afford to use commercial fertilizers? From the facts presented in previous chapters, the conclusion is inevitably reached that only by painstaking observation of all the factors which effect increased production, coupled with actual tests of fertilizers in the field by persons who are willing to make a somewhat careful study of the conditions present, can the question be answered with any degree of accuracy.

If a given quantity of fertilizers be applied to imperfectly fitted land and the result is profitable, is it any indication that equally good results might not have been reached without fertilizers had better tillage been given? Too frequently, fertilizers are made to take the place of tillage, when they should be used to supplement it. That is, fertilizers are most likely to produce profitable results when conjoined with superior physical conditions of soil. The appropriate quantities and kinds can only be determined by actual investigation, and by using various mixtures of known composition. Instead of purchasing several brands of fertilizers to secure relatively larger or smaller amounts of nitrogen, phosphoric acid and potash, it is usually best to purchase these substances separately, of reliable dealers, whose guarantee can be trusted, and mix them in such proportions as experience shows to be best. It is usually more economical to purchase high-grade than low-grade products, since the soil usually contains enough low-grade plant-food, and since something is saved in packages and transportation, and

labor of applying them. In the purchase of high-grade products, there is the satisfaction of securing what is wanted, without purchasing and handling what is not wanted.

It is sometimes asserted that commercial fertilizers tend to deplete the soil, and there is some truth in this notion when they are used under certain conditions. Not infrequently it occurs that an application of two hundred to three hundred pounds of commercial fertilizers per acre increases the yield five to fifteen bushels of wheat, and in some cases such application makes the difference between a failure and a fairly full crop, so marked are the beneficial effects of fertilizers on some soils. But unless some measures are taken to unlock the elements in the soil by extra tillage, provided the soil contains an abundance of tough plant-food, or living plants or manures, or both, be used to reinforce the land, diminished productivity must come on more rapidly than it would have done if no fertilizers had been used. The unscientific use of commercial fertilizers has led many a farmer to conclude that they injure the land by reason of their "stimulating" effect. Observation has led to the conclusion that in many cases the yield of grain steadily diminished where only a few hundred pounds per acre of fertilizers were used and the old methods of tillage and treatment of the land continued, and the effect of the fertilizers was likened to the effect of alcohol on the confirmed toper; but to stop meant collapse, and to go on implied constantly increased use.

Commercial fertilizers do not stimulate plant growth, in the sense in which the word is commonly used. They do stimulate by furnishing true nourishment; then how can the observed effect be explained? It is well known that plants frequently suffer from lack of a full supply of food at the critical period of their growth. When they have used the easily available food stored in the seed, but have not yet had time to form roots sufficiently numerous to secure a full supply of nourishment from that which is less available in the soil, the addition of easily available concentrated nourishment is of the greatest value. Most land is so imperfectly fitted for the highest welfare of plants that unless a small amount of tender plant-food be placed in juxtaposition to the seed, growth languishes until the plant has extended and multiplied its roots sufficiently to secure a supply of nourishment from the tough and less concentrated constituents stored in the soil. If, then, some easily available nourishment is at hand to sustain the plant, and keep it in full vigor during the transition from seed to soil, it is evident that a larger crop will be secured than would have been obtained if no additional nourishment had been furnished; and this quick start, when compared with unfertilized plants, appears to the farmer to be a stimulation.

The amount of valuable elements removed from the soil by the increased yield, due to the action of the fertilizer, is sometimes greater than the amount of these elements added by the fertilizer; thus the

drain upon the soil is greater than it would have been had no fertilizer been applied. Notwithstanding this, the application of small amounts of high-grade fertilizers is not only rational, but usually profitable, if used in conjunction with cover crops, barn manure and intelligent rotation. Nevertheless, their use alone too often assists in depleting the soil of its fertility to the point where profitable tillage ceases, and if the practice of using only small amounts of fertilizers is continued it may, as shown above, accelerate soil depletion. The productivity of the land may be, and often is, maintained and even increased by the intelligent application of liberal amounts of fertilizers in connection with a judicious rotation and wisdom in farm-management.

It is believed that the beneficial effects of commercial fertilizers are due as much to the timely supply as to the amount of nourishment they contain. This timely supply enables the plants to enlarge their root system, whereby they are able to secure more nourishment from the soil over and above that furnished by the fertilizers, than they could have secured without such supply. If this be so, it is seen again that the use of fertilizers in small quantities may not only largely increase the yield of crops, but may also serve to deplete the soil of some of its elements of plant-food more rapidly than would the same kind of crops and treatment without their use.

Much has been said and written about complete fertilizers, that is, those which contain nitrogen, phos-

phoric acid and potash in the proportions found in the plants to be grown. But plants vary widely in amounts and proportions of nitrogen, phosphoric acid and potash; the variations are due to many causes, such as an abundance or lack of moisture, sunshine, and inherited power of the plants. Then, too, the soil varies more widely in the percentage of plant-food and its availability than the plants do. Usually it is desirable to increase the leaves and stalks,—the vegetative system,—of plants intended simply for forage; this can be done by supplying them with an abundance of nitrogen, while the production of grain and some tubers and roots is best secured by using moderate quantities of nitrogen and liberal quantities of available phosphoric acid and potash.

Many efforts have been made to determine the limit to the profitable use of commercial fertilizers. Manifestly no definite conclusions can be reached which may serve for general application. If the investigations be carried on with a single crop, as wheat, for a long series of years, the soil becomes abnormal, since twenty to forty years' continuous wheat culture, as conducted by Lawes and Gilbert, depletes the soil of its humus, and hence of its power to hold moisture and to set free phosphoric acid. Then, too, no account is taken, usually, of the amount and availability of the stores of plant-food already in the soil. For instance, if mineral fertilizers alone be used and but slight increase is secured, the natural conclusion would be that there was as much mineral matter present as the plants could utilize, or that they could

not avail themselves of it because of a lack of moisture or some necessary element or elements; but such investigation does not reveal positively the real cause of low production. If a complete fertilizer is used, no matter whether such application is profitable or unprofitable, the problem still remains unsolved, for a fertilizer which contains relatively little mineral matter and a liberal amount of nitrogen, as compared with a complete fertilizer, might give profitable increase, as has happened in some of the experiments conducted in this country and Europe; yet no general rule is revealed.

SOME SPECIFIC ADVICE AS TO FERTILIZERS AND CROPS.

There appears to be no way to find a universal rule to guide the farmer as to the kinds or quantities of commercial fertilizers which are likely to produce the greatest profitable results. A law does appear which is of very general application, namely, the higher the price realized for the products raised, the more liberal the application may be without exceeding the limit of profit. There seems to be no alternative but to again send the farmer to the field, and admonish him to make the plants comfortable by tillage and by the best possible use of the elements in the soil, and to keep a fairly tight grip on the phosphate sack until he has questioned the soil and the plants, and has received their answers. He must experiment for himself.

It, therefore, requires judgment and some experience to know when and where to apply commercial fertilizers to the best advantage. If the effects of commercial fertilizers, when applied intelligently, are noted, it will be observed that they usually produce beneficial results by furnishing easily available nourishment to the plants in the earlier stages of their growth, as already explained; therefore it is advisable to distribute them in the soil near the seeds, that nourishment may be at hand in sufficient abundance to give the young plants a vigorous and healthy start in life.

If liberal applications of nitrogen are made, as for instance, to winter wheat and fruit plantations, in September, they may produce such rapid and sappy growth as to endanger the plants. Rust or damage from cold weather frequently occur when plants have made a late and immature growth. In the case of wheat and some other crops, it may be well to withhold a part or all of the nitrogen in the fall, or make an application of somewhat slow-acting organic nitrogen, as cotton-seed meal. Plants often suffer seriously for want of available nitrogen when they are recovering from the injury of winter exposure. Quick-acting nitrogen, such as nitrate of soda, is especially beneficial in assisting them to a strong, early start. Later in the season, when nitrification is active, they may get their supply normally from the soil.

Some soils respond to applications of commercial fertilizers far more satisfactorily than others. Why

this is so is difficult to explain. Sometimes the soil has become too acid, as shown by the investigations of the Rhode Island Experiment Station (see Chapter XIII.); in other cases the causes which produce the widely different results are wholly obscure. On both sides of the head of Cayuga Lake, in New York, and for some distance to the southward, only small amounts of fertilizers are used, while to the northward of this district they are used liberally and with markedly beneficial results. It would naturally be supposed that the first-named district would be the one to be most benefited, since the natural fertility of the land is far inferior to that of the district lying to the north of it. Many tests of fertilizers have been made in the southern district with and without applications of lime, and only in rare cases increased yield has justified such application. In the northern districts several carloads of fertilizers are sold annually at each of the little villages on the lines of railways, while in the southern a very few carloads serve for a wide extent of territory. In making a survey of some of the middle states, it is found that in certain sections fertilizers are in common use, while in others they are used sparingly or not at all.

When inquiry is made as to the cause of use or non-use of fertilizers, the answer in one section is, "It pays, and therefore I cannot afford to do without them"; in the other, "It does not pay, and therefore I cannot afford it." Usually the first answer comes from farmers who till soils which are naturally

adapted to a vigorous growth of a wide range of plants. True, the people who farm the better lands are, as a rule, more progressive than those are who farm the poorer lands, but this does not fully explain why fertilizers are used liberally in one locality and sparingly in another. Where land is expensive and near good markets, soils which were naturally poor have been brought to a high state of production largely by the aid of manures.

Since barn manures are bulky and expensive to transport and distribute, would it not be better economy, instead of purchasing barn manures from the city stables, to get some of the humus for the soil by raising cover and catch crops for green manure, and then secure the additional plant-food needed by the more liberal use of commercial fertilizers? In market-gardening, rapid, early growth is usually desirable, and it is likely that these results could be secured through the quick-acting fertilizers, in connection with barn manures and cover crops, more economically than through the slower-acting manures alone. (See Chapter XIV.)

Fertilizers usually give best results when they are well mixed with the soil which lies near to and around the seeds when they are planted. Liberal applications of high-grade fertilizers, especially if applied when the soil is dryish, may do serious injury by absorbing the moisture in the soil, thereby arresting germination, or by furnishing plant-food which is too concentrated for the young rootlets, in which case the roots are injured, and are said to be "burned

off." When moisture is abundant, no damage is likely to occur, since the fertilizers then tend to become diffused through the soil, but it is not only safest, but most economical, to incorporate the fertilizer with some of the soil in the drill or row. The quantity to be applied can be determined only by trial, having in mind that a residue always remains unused by the crop to which it is applied, in which case it may be of some value to succeeding crops.

In some cases the beneficial action of fertilizers may be marked on the crop which grows with and immediately after the one to which they are applied; for instance, fertilizers applied to wheat and similar crops may benefit the timothy and clover seeding as much as the wheat. In fact, it not infrequently happens that but a poor or even no "stand" of grass can be secured without the use of fertilizers on the wheat, whereas by their use a successful "catch" is secured.

ESTIMATING THE COMMERCIAL VALUE OF FERTILIZERS.

Efforts have been made to determine the trade values or cost of nitrogen, phosphoric acid and potash. It is evident that the cost must be governed, to some extent, by locality and other conditions; for instance, the nitrogen, phosphoric acid and potash in a ton of cotton-seed meal has an estimated trade value, according to the illustrative table below, of

$23.64 per ton. It sells in the south at from $16 to $19 per ton.

TABLE LXXXI.

Average of 33 analyses of cotton-seed meal.

(Bul. 20, So. Ca. Exp. Sta., 1895.)

Moisture.	Phosphoric acid. Soluble.	Citrate-soluble.	Available.	Insoluble.	Total.	Nitrogen.	Equivalent to ammonia.	Potash soluble in water.	Relative commercial value per ton.
7.37 %	1.33 %	1.25 %	2.58 %	.18 % *	2.76 %	6.75 %	8.19 %	1.66 %	$23.64
Estimated trade value per pound			4.5 ¢			14.5 ¢		5 ¢	

The following table gives trade values, based on prices at a given time and place, which serve to assist in making comparisons of various substances:

TABLE LXXXII.

Trade values of fertilizing ingredients in raw materials and chemicals.†

	1896. Cts. per lb.
Nitrogen in ammonia salts......................................	15.
" " nitrates..	13.5
Organic nitrogen in dry and fine ground fish, meat, blood, and in high-grade mixed fertilizers..........	14.
" " " cotton-seed meal	12.
" " " fine ground bone and tankage.............	13.5
" " " " " medium bone and tankage	12.

*The law of South Carolina gives no trade value to insoluble phosphoric acid.

Before proceeding further it should be stated that the term insoluble is applied to phosphoric acid which is insoluble in a solution of neutral ammonium citrate having a specific gravity of 1.09 at a temperature of 65° Centigrade.

† Bull. 42, Mass. Hatch Exp. Sta., 1896.

	1896. Cts. per lb.
Organic nitrogen in medium bone and tankage	9.
" " " coarse bone and tankage	3.
" " " hair, horn shavings and coarse fish scraps.	3.
Phosphoric acid soluble in water	5.5
" " " " ammonium citrate	5.
" " in fine bone and tankage	5.
" " " " medium bone and tankage	4.
" " " medium bone and tankage	2.5
" " " coarse bone and tankage	2.
" " " fine ground fish, cotton seed meal, linseed meal, castor pomace and wood ashes	4.5
" " insoluble (in ammonium citrate) in mixed fertilizers	2.
Potash as high grade sulphate, and in mixtures free from muriate	5.
" " " muriate	4.5

The manurial constituents contained in feed stuffs are valued as follows:

Organic nitrogen	12.
Phosphoric acid	4.5
Potash	5.

"The above trade values are the figures at which, in the six months preceeding March, 1896, the respective ingredients could be bought at *retail for cash in our large markets, in the raw materials*, which are the regular source of supply."

While the preceding table gives the trade values of fertilizing ingredients in raw materials and chemicals in the six months preceding March, 1896, it gives no information as to the prices the farmer paid for nitrogen, phosphoric acid and potash when purchased from agents in the ordinary mixed commercial fertilizers which were found on the market. Since the economic production of crops, as governed by the use

and cost of fertilizers, must depend largely on the actual cost of them to the farmer, it may be well to determine so far as it is possible what that cost is, at least in one State.

W. H. Jordan, Director of the New York State Experiment Station, has made an extended study of this subject, and since the execution of the laws governing the fertilizer trade is assigned to the State Station, he has had unusual facilities for securing accurate information. By permission, I publish the following letter from him, dated Geneva, N. Y., March 5, 1897:

"Taking the average composition of the factory-mixed complete fertilizers which were offered for sale in New York last year, together with the selling price as given us by the agents, we find that the average price per pound for nitrogen would be 20.2 cents; available phosphoric acid, including the soluble, 8 cents; potash, soluble in water, 6.5 cents. These figures were arrived at in this way:

"We found that the average selling price for these goods was a certain percentage above the prices for which similar materials could be bought near large markets. In order, then, to get the prices which the farmers were asked to actually pay, we simply increased these so-called Station valuations just the percentage which the retail factory-mixed goods are selling above what the same goods would cost if bought according to Station valuation."

It will not be difficult for the farmer to compare the average price paid in New York for nitro-

gen, phosphoric acid and potash in factory-mixed complete fertilizers, in 1896, with the retail cash price, as given in Table LXXXII. Having shown what the trade values of various ingredients were in our large markets in 1896, and the average cost to the user for the same ingredients in the same year, it must now be left to the farmer to decide for himself whether he will purchase plant-food in the various forms of raw material or in factory-mixed fertilizers. (See "Home Mixing of Fertilizers," page 289.)

The trade value or cost of many fertilizing substances may be determined approximately, but how much any given fertilizer may be worth to the user of it cannot be determined until a trial of it has been made in the field, and as soon as this is done so many complications enter into the investigation that it requires a clear understanding to interpret the results. High-grade fertilizers are often applied to soils which contain only a moderate supply of available plant-food, with no marked benefits. In such cases the manufacturer may be accused of selling a poor quality of goods at exorbitant prices. In some cases, it is probable that, had the purchaser of the fertilizer used as much intelligence in securing good seed and comfortable conditions for the plants as the manufacturer of reliable fertilizers is compelled to use in his business, the results might have been entirely satisfactory.

An earnest effort should be made on the part of the farmer to give fertilizers full opportunity to

produce results, for only by so doing can any true test be made of their value. That such opportunity is not given in many cases is fully proved by the fact that the farmers who are most painstaking in selecting seed and in preparing the land for a crop purchase fertilizers more freely than those do who are careless in their farm operations. On the other hand, the manufacturers should take pains to make the statement of the percentages of the valuable constituents in their goods so plain that fair comparisons could be made easily. Nearly all of the old, well-established firms make a fairly clear statement on the tags attached to their packages, but many fertilizers are placed on the market with confusing statements as to their composition. The two following samples, copied from manufacturers' tags, have the appearance of an effort to confuse the purchaser and to prevent him from arriving at any basis for comparisons:

SAMPLE I.

Analysis.

	Per cent.		
Ammonia	3.	to	4.
Phosphoric acid (soluble and reverted)	10.	"	12.
Phosphoric acid (insoluble)	1.	"	2.
Total phosphoric acid	11.	"	14.
Potash K_2O (actual)	1.62	"	2.16
Sulfate of potash	3.	"	4.

Suppose the tag had given the following analysis, unaccompanied by any statements which are not understood by the farmer, the estimated value could have been easily made out by the purchaser:

Manufacturer's guaranteed analysis simplified.

	Per cent.
Nitrogen	2.47 to 3.29
Phosphoric acid, soluble	7. " 8.
" " reverted	3. " 4.
Potash (K_2O)	1.62 " 2.16

Estimated value per ton.

Nitrogen	49.4 lbs.	at 14	cents,	$6.92
Phosphoric acid, soluble	140. "	" 5.5	"	7.70
" " reverted	60. "	" 5.	"	3.00
Potash	32. "	" 4.5	"	1.44
				$19.06

This fertilizer was retailed at $30 per ton.

SAMPLE II.

Analysis.

	Per cent.
Nitrogen	3. to 4.
Phosphoric acid, soluble	8. " 9.
" " reverted	2. " 3.
Potash	4. " 5.

Estimated value per ton.

Nitrogen	60 lbs.	at 14	cents,	$8.40
Phosphoric acid, soluble	160 "	" 5.5	"	8.80
" " reverted	40 "	" 5.	"	2.00
" " insoluble	30 "			
Potash	80 "	" 4.5	"	3.60
				$22.80

The retail price being $30 per ton, leaves $7.20 to cover cost of mixing, sacks, transportation, agent's commission, interest on deferred payments, sundry incidental charges, and profits.

The following figures are also copies of tags attached to commercial fertilizer sacks. It must be left to those

who concocted them to give the reasons for this work of supererogation :

SAMPLE III.

Ammoniated bone phosphate.

	Per cent.
Nitrogen	1.03 to 1.65
Equivalent to ammonia	1.25 " 2.
Soluble phosphoric acid	6. " 7.
Reverted " "	5. " 6.
Available " "	11. " 13.
Insoluble " "	2. " 3.
Total " "	13. " 16.
Potash	3. " 5.

SAMPLE IV.

Harvest bone.

	Per cent.
Total bone phosphate	30 to 35
Yielding phosphoric acid	14 " 16
Soluble bone phosphate	22 " 26
Yielding water soluble phosphoric acid	10 " 12
Total available bone phosphate	26 " 30
Available phosphoric acid	12 " 14
Insoluble bone phosphate	2 " 4
Yielding insoluble phosphoric acid	1 " 2

SAMPLE V.

Special potato manure.

	Per cent.
Moisture	10. to 15.
Ammonia	2. " 2.25
Available phosphoric acid	8. " 9.
Equivalent to bone phosphate of lime	20.74 " 24.01
Insoluble phosphoric acid	1.25 " 2.
Potash	8. " 8.50
Equivalent to sulphate	11.80 " 13.72

Simplified statement of sample iii.

	Per cent.	Per ton.	Estimated value.
Nitrogen	1.03	20.6 lbs. at 14 cents,	$2.88
Soluble phosphoric acid	6.	120. " " 5.5 "	6.60
Reverted " "	5.	100. " " 5. "	5.00
Potash	3.	60. " " 4.5 "	2.70
			$17.18

Simplified statement of sample iv.

	Per cent.	Per ton.	Estimated value.
Soluble phosphoric acid...	10	200 lbs. at 5.5 cents,	$11.00
Reverted " " ...	2	40 " " 5 "	2.00
			$13.00

Simplified statement of sample v.

	Per cent.	Per ton.	Estimated value.
Nitrogen	1.65	33 lbs. at 14. cents,	$4.62
Available phosphoric acid	8.	160 " " 5. "	8.00
Potash	8.	160 " " 4.5 "	7.20
			$19.82

What information can a farmer get from the following guaranteed analysis, which is copied, as are the quotations below, from the New York Agricultural Experiment Station:

SAMPLE VI.

"'*Natural plant-food.*

	Per cent.
"'Phosphoric acid. Total (P_2O_5)................	21.60 to 29.49
Equivalent to bone phosphate of lime	27.20 " 64.38
Potash (K_2O) from glauconite	1.00 " 2.00
Equivalent to common sulfate of potash	2.00 " 4.00
Silicic acid (SiO_2)	5.26 " 8.10
Carbonic acid (CO_2)	2.07 " 3.00
Lime (CaO)	29.16 " 32.00
Magnesia (MgO) and soda (Na_2O)............	3.21 " 8.05
Aluminic (Al_2O_3) and ferric (Fe_2O_3) oxids	5.14 " 10.26

'All available to plants in the soil. The above are the lowest and average analyses.'"

"The guaranteed analysis implies, and a specific claim is made, that the material is all available to plants in the soil."*

The New York State Station has performed a valuable service in showing in a brief statement the percentages of available phosphoric acid and potash in this fertilizer with a high-sounding name, which was retailed, including the name,—which must have had great value,—at from $25 to $28 a ton. "An average of three samples shows the following composition:

	Per cent.
"Total phosphoric acid	22.21
Insoluble phosphoric acid	20.81
Available phosphoric acid	1.40
Potash soluble in water	.13"

"Natural Plant-food" is really a mixture of some rock phosphate (probably Florida soft phosphate) with glauconite, a mineral containing potash in an insoluble form, commonly known as "green sand marl."

Computing this, as in previous cases, the following estimated values are secured;

			Per ton.
Available phosphoric acid	28. lbs.	at 5 cents,	$1.40
Potash	2.6 "	" 4.5 "	.12
			$1.52

"The law of Georgia does not recognize insoluble phosphoric acid as plant-food."† This would appear

*Bull. 108, N. Y. Agr. Exp. Sta., Geneva, N. Y. New Series, Sept. 1896. The real value of "Natural Plant-food," L. L. Van Slyke, Ph.D., chemist.

†I am credibly informed that in several other southern states insoluble phosphoric acid is treated as in Georgia.

to be a wise provision, since insoluble plant-food is not what is usually wanted in a fertilizer, as the soil contains great abundance of it. In Table II., Chapter I., the average of forty-nine soil analyses shows that more than 4,000 pounds per acre of phosphoric acid are contained in the first eight inches of surface soil, the larger part of which, presumably, is insoluble under present methods of tillage. Would it be wise or profitable to purchase, at 2 cents per pound, additional insoluble phosphoric acid, when the soil contains such vast stores of this low-grade plant-food? True, a part of the so-called insoluble phosphoric acid may become available and produce beneficial results, but since the soil is usually abundantly supplied with the same kind of material, would it not be wiser to make it available by tillage than to purchase more of this lazy plant-food?

In some cases liberal applications of insoluble phosphoric acid show beneficial results. If two pots be filled from the same kind of soil, and to one is added insoluble phosphoric acid, plants growing in the treated soil should be benefited, since their roots would, of necessity, come in contact with more insoluble phosphoric acid in the treated than in the untreated soil. The roots of plants, some more than others, are able to utilize a small portion of the so-called insoluble phosphoric acid; hence it cannot be said to be worthless. Some Stations give to insoluble phosphoric acid in mixed fertilizers an estimated trade value of 2 cents per pound, while others assign to it no trade value whatever. Nevertheless, there may be

exceptional cases where, on account of the small cost of insoluble phosphoric acid, it could be applied advantageously and even with profit.

It will be seen by the foregoing that there is a difference of opinion as to the value of so-called "insoluble phosphoric acid." If the reader believes that it is worth to him 2 cents per pound, then the previous computations should be amended, and the following amounts should be added to the computed value: To sample I., 40 cents; II., 60 cents; III., 80 cents; IV., 40 cents; V., 50 cents, and to VI., $8.32 per ton.

This "Natural Plant-food" has been treated at length, and it is an extreme example of what is and has been taking place to a greater or less extent in many localities where fertilizers are used, notwithstanding that intelligent efforts have been made to guard the rights of users of commercial plant-food.

The subjects of values, estimated values, and use of fertilizers are surrounded with many difficulties, but this fact should act as a spur to increased effort to learn what we may, although we may never come to unanimous conclusion as to the trade value or actual value of various kinds of plant-food, or be able to treat the subject mathematically. When fertilizers which are sold at nearly the same price vary in estimated value, as computed by their guaranteed analyses, from $3 to $20 per ton, the fact is worth knowing. If unmixed fertilizers containing a known percentage of nitrogen, phosphoric acid and potash are separately purchased, opportunity is given to

make tests on small areas at a slight cost, as they can be mixed in variable quantities to suit the soil and the crop to be raised.

While esteeming the efforts which are being made by manufacturers for promoting the farmer's interests, I am led to urge the farmer to do a little more thinking for himself. Some of the manufacturers make careful and extended experiments with their fertilizers in the field, with the view of discovering how best to compound nitrogen, phosphoric acid and potash. When large sums are invested in this business, it would be bad policy to send out goods which would not, as a rule, give satisfactory results, otherwise the business would soon come to an end. However valuable these manufacturers' tests may be, they cannot take the place of those which should be made by every farmer who uses fertilizers upon his own soils and under his particular conditions. It has been pointed out how variable the virgin soil is, and this soil has been made still more variable by tillage and cropping; hence the need of careful fertilizer tests by the farmer on his own fields, since no test made elsewhere will tell certainly what he wants to know.

HOME MIXING OF FERTILIZERS.*

It is believed that the following explanations will be of assistance to the young farmer in his efforts to make an intelligent use of commercial fertilizers.

---

* By L. A. Clinton, Assistant Agriculturist, Cornell Exp. Sta.

In the home mixing of fertilizers, it is frequently desirable to know what percentage of the different elements is contained in the mixture. We will assume that it is wished to compound a fertilizer made up of materials combined in the following proportion:

	Lbs.		Per cent.
Nitrate of soda	100	guaranteed	15 nitrogen.
Acid phosphate	500	"	12 phosphoric acid.
Muriate of potash	100	"	50 potash.
	700		

We have a mixture of 700 pounds of material containing 15 pounds of nitrogen, 60 pounds of phosphoric acid, and 50 pounds of potash. To find the percentage of each of the elements, divide the amount of each element by the total amount of the mixture. In the assumed case the calculation would be as follows:

	Per cent.
Nitrogen	15 ÷ 700=2.14 nitrogen.
Phosphoric acid	60 ÷ 700=8.57 phosphoric acid.
Muriate of potash	50 ÷ 700=7.14 potash.

If it should be desired to compound a fertilizer for wheat, using as the materials sulfate of ammonia, dissolved bone and kainit, we will assume that they are combined in the proportions and have the guaranteed analyses as given below:

	Lbs.		Per cent.
Sulfate of ammonia	80	guaranteed	24 ammonia.
Dissolved bone	200	"	14 phosphoric acid.
			2 nitrogen.
Kainit	200	"	13 potash.
	480		

We have a mixture of 480 pounds, the sulfate of ammonia containing 19.20 pounds of ammonia, of which $\frac{14}{17}$, or 15.8 pounds, is nitrogen. The dissolved bone contains 2 per cent nitrogen, or 4 pounds. There is a total of 19.8 pounds of nitrogen, 28 pounds of phosphoric acid, and 26 pounds of potash. The percentage of each element in the mixture will now be calculated as in the previous case:

		Per cent.
Nitrogen	19.8 ÷ 480 =	4.12 nitrogen.
Phosphoric acid	28. ÷ 480 =	5.83 phosphoric acid.
Potash	26. ÷ 480 =	5.41 potash.

Thus having given the ingredients of the mixture, and knowing the amount and guaranteed analysis of each ingredient, it becomes an easy matter to determine how many pounds, and the percentage of the valuable elements, are being applied per acre.

In case it is wished to compound and apply a mixture of 500 pounds which shall analyze 4 per cent nitrogen, 6 per cent potash, and 10 per cent phosphoric acid, and assuming that the materials at hand are nitrate of soda guaranteed 15 per cent nitrogen, dissolved phosphate rock guaranteed 18 per cent phosphoric acid, and muriate of potash guaranteed 50 per cent potash, the calculation would be made as follows:

A mixture of 500 pounds, to contain 4 per cent nitrogen, calls for 20 pounds of nitrogen; 6 per cent potash calls for 30 pounds of potash; 10 per cent

phosphoric acid calls for 50 pounds phosphoric acid. To determine how many pounds of each ingredient are required to furnish the necessary amount, divide the number of pounds of each element in the mixture by the guaranteed per cent of the element in the ingredient. In the case in hand the determinations would be as follows:

Element.	Lbs. required.	Guaranteed per cent in ingredient.	Lbs. of ingredient required.
Nitrogen.........	20	15 %	133 nitrate of soda.
Phosphoric acid..	50	18 "	277 dissolved phosphate rock.
Potash...........	30	50 "	60 muriate potash.
Total pounds of ingredients..			470

It will be seen that the total weight of the ingredients is but 470 pounds. To supply the additional 30 pounds required to make the 500 pounds of fertilizer, it will be necessary to add some extraneous material, as fine road-dust or gypsum. The addition of extraneous matter to a mixture of high-grade chemicals is advisable only because it facilitates the even distribution of the fertilizer over the land, and in the use of high-grade chemicals this even distribution is most important. Should it be so distributed that a considerable amount was left in spots, the plants, especially if young and tender, would probably be destroyed or injured on those places. It is usually better to purchase high-grade chemicals and add the extraneous material at home, if thought best, rather than to pay others for add-

ing it, and then pay freight and carriage to the place of consumption.

The objection to the home mixing of the materials is that the work may not be properly done. This is an important operation, and should be most thoroughly performed. A tight, smooth floor is the first requisite. It is usually well to have the materials for the mixture each in a separate pile, and so arranged that they can be easily shoveled at the same time into one common lot. Afterwards the whole mass should be thoroughly mixed, by shoveling it over several times. It should be said that usually the mixing should be done but a short time before the material is to be used, and that compounds containing ammonia should not be mixed with lime.

If from the following materials we make a ton of mixture, we would have to calculate the needed amounts as follows:

	Per cent.	
Sulfate of ammonia	20.	nitrogen = 400 lbs. nitrogen in a ton.
Cotton-seed meal............	7.	" 140 " " " " "
	2.5	available phosphoric acid = 50 lbs. " " " " "
	1.9	water soluble potash = 19 lbs. potash " " "
Acid phosphate	15.	available phosphoric acid = 30 lbs. " " " " "
Muriate of potash...........	50.	water soluble potash = 1,000 lbs. potash " " "

If we desire to mix the ingredients to make a fertilizer with any percentages of the three valuable ingredients, say 5.5 per cent each of nitrogen, phosphoric acid and potash, we proceed as follows:

Per cent.
2,000×5.5=110 lbs. nitrogen required in a ton.
2,000×5.5=110 " phosphoric acid required in a ton.
2,000×5.5=110 " potash required in a ton.

Out of this 110 pounds of nitrogen, we wish 2.5 per cent, or 50 pounds, of it to come from sulfate of ammonia and the rest from cotton-seed meal. Twenty per cent is 20 pounds out of the 100 pounds, and 20 per cent nitrogen in sulfate of ammonia is 20 pounds nitrogen out of the 100 pounds of sulfate of ammonia. Then from a simple proportion:

Nitrogen is to		sulfate of ammonia on hand	as	nitrogen needed	is to	sulfate of ammonia required.
20 lbs.	:	100 lbs.	: :	50 lbs.	:	250 lbs.

This 250 pounds of sulfate of ammonia gives 50 pounds of nitrogen, or 2.5 per cent for 50÷2,000=2.5 per cent. We need 3 per cent of nitrogen still to give us the required 5.5 per cent. It follows, then, that 2,000×3 per cent=60 pounds, to be supplied by the cotton-seed meal, which has 7 per cent nitrogen or 7 pounds of nitrogen to the 100 pounds of raw material. Then again, by proportion:

Nitrogen.		Cotton-seed meal.		Nitrogen needed.		Cotton-seed meal.
7 lbs.	:	100 lbs.	: :	60 lbs.	:	857 lbs.

This 857 pounds cotton-seed meal gives 59.99 pounds nitrogen. Adding now the amount of nitrogen obtained from the 250 pounds sulfate of ammonia (50 pounds) to that obtained from the 857 pounds cotton-seed meal (60 pounds), we have the 110 pounds of nitrogen wanted. In the cotton-seed meal we

have 2.5 per cent of phosphoric acid and 1.9 per cent of potash; so—

875×2.5 per cent = 21.43 pounds of phosphoric acid,

and

857×1.9 per cent = 16.28 pounds of potash.

Subtracting the 21.43 pounds of phosphoric acid from the original 110 pounds wanted, we have:

110−21.43 = 88.57 pounds phosphoric acid.

This 87.57 pounds is to be obtained from the 15 per cent acid phosphate. Proceeding as before:

Phos. acid.		Acid phosphate.		Phos. acid needed.		Acid phos. required.
15 lbs.	:	100 lbs.	: :	88.57 lbs.	:	590.46 lbs.

Adding the amounts of phosphoric acid obtained from the 857 pounds cotton-seed meal, which is 21.43 pounds, and from the 590.46 pounds of acid phosphate, which is 88.57 pounds, we have the 110 pounds of phosphoric acid needed.

Continuing similarly for the potash, and subtracting the 16.28 pounds of potash obtained from the 857 pounds of cotton-seed meal, we have 93.72 pounds to be obtained from the muriate of potash, which has 50 per cent, or 50 pounds, of potash to the 100 pounds; then—

Potash.		Muriate potash.		Potash needed.		Muriate pot. required.
50 lbs.	:	100 lbs.	: :	93.72 lbs.	:	187.44 lbs.

Adding together the 16.28 pounds of potash

obtained from the cotton-seed meal and the 93.72 pounds obtained from the muriate of potash, we have the desired 110 pounds of potash. If the raw materials do not add up to 2,000 pounds, fine sand or gypsum may be added, in order to make the exact weight and exact percentages, or if desirable, higher or lower percentages may be had by mixing differently. Summing up, in order to see if our mixture is all right, we have:

Per cent.			Nitrogen.	Phos. acid.	Potash.
20.	Sulfate of ammonia	250. lbs.	= 50 lbs.		
7. / 2.5 / 1.9	Cotton-seed meal	857 "	= 60 "	21.43 lbs.	16.28 lbs
	Acid phosphate	590.46 "		88.57 "	
	Muriate of potash	187.72 "			93.72 "
		1,885.18 "	110 "	110.	110.
	Sand or dirt	114.82 "			
		2,000.00 "	= 5.5%	5.5%	5.5%

It is seen again that it is better to buy the three elements of plant-food separately in concentrated forms and to mix them at home.

The foregoing calculations by Mr. Clinton sufficiently indicate the nature of the problem before us. The author is now able to make general conclusions. The following quotation is taken from a paper read by T. Greiner before the Massachusetts Horticultural Society, February 20, 1897: "I can see no necessity for using ready-made mixtures in the garden, but the strongest reasons for avoiding that course. The mixtures sent out by various firms as

specially adapted for garden crops vary in real value between $20 and $26 per ton, and sell at from $30 to $40. In other words, we pay the full value and 50 per cent additional to make expenses and losses, as well as seller's profit. In the following—

500 lbs.	nitrate of soda, costing about	$11.25
1,200 "	dissolved S. C. rock, costing about	6.00
300 "	muriate of potash, costing about	6.75
2,000		$24.00

we have a ton which is worth $27.90, and equal to a fertilizer sold by manufacturers at about $40."

An effort has been made to treat the subject of the trade values and home mixing of commercial fertilizers simply and clearly; nevertheless, the farmer untrained in chemistry will have to make a study of the tables and explanations before he can compute estimated values, or make intelligent comparisons between two fertilizers having an honest guaranteed analysis. It has been shown how widely the estimated values, in some cases, differ from the selling price in various brands of fertilizers. It must now be left to the farmer to work out trade values, estimated values, and the actual values to him of the goods he purchases. It should be remembered, however, that the manufacturer may charge a dollar an hour for his services in making estimates, while the farmer may receive not more than a dollar a day for his time. Would it not be better for the farmer to fit himself for making these computations, and thus secure the more liberal remuneration?

A WORD ON THE CHEMISTRY OF THE SUPER-PHOSPHATES.*

In many parts of the country the word superphosphate is understood by farmers to be simply another name for commercial fertilizers; but in the books, it is used in its true meaning, to designate a super-phosphated fertilizer. When a superphosphate is applied to the soil, it is with the intention of furnishing available phosphoric acid. Soluble phosphoric acid is desired because plants feed most readily upon those elements in the soil that are most easily dissolved. Phosphoric acid as it exists in nature, either in bones, bone deposits, or rocks, is almost always in an insoluble condition; hence, if we would apply it in an available form, that found in nature must be treated in some way. How is this done?

Before considering the chemical principles upon which the manufacture of a superphosphate rests, it will be necessary to understand something of the different compounds which phosphoric acid forms with lime. Phosphoric acid is represented by P_2O_5, in which P represents the element phosphorus, and O the element oxygen, and the figures 2 and 5 that phosphoric acid is made by the combination of two parts of phosphorus and five of oxygen. Similarly, lime is represented by CaO, to show that it is composed of one part of the element calcium (Ca) and one part of oxygen. By an element, is meant any substance which cannot be separated by any possible

*By George W. Cavanaugh, Assistant Chemist of the Cornell Exp. Sta.

means into any other substances. Whenever two or more elements enter into combination to form a new substance, this new substance is called a compound. For example, phosphorus (P) and oxygen (O) are elements, but phosphoric acid (P_2O_5) is a compound. Not only do elements combine to form compounds, but many of the compounds themselves combine again to form more complex compounds. Thus calcium (Ca) and phosphorus (P) each unites with oxygen (O) to form lime (CaO) and phosphoric acid (P_2O_5); and then the lime and phosphoric acid may unite to form phosphate of lime.

Phosphoric acid (P_2O_5), as found in bones and rocks, is united with three parts of lime. This compound may be represented by the formula $\left\{\begin{matrix} CaO \\ CaO \\ CaO \end{matrix}\right\} P_2O_5$. This material is called tricalcium phosphate, because it contains three parts of lime or calcium oxid (CaO) united with one part of phosphoric acid (P_2O_5). This is the form of phosphoric acid that is known as "insoluble phosphoric acid," because the compound does not dissolve in water.

A second form in which phosphoric acid may unite with lime is represented by the formula $\left\{\begin{matrix} CaO \\ CaO \\ H_2O \end{matrix}\right\} P_2O_5$. Here the phosphoric acid is united to two parts of lime and to one part of water (H_2O), water being a compound containing two parts of the element hydrogen (H) and one part of oxygen. This compound is dicalcium phosphate. It is soluble in soil water, which contains carbonic acid (CO_2).

A third form has the phosphoric acid united to one

part of lime and two parts of water. This compound is represented by the formula $\left.\begin{cases} CaO \\ H_2O \\ H_2O \end{cases}\right\} P_2O_5$. Since this compound has but one part of lime (or calcium oxid), it is called monocalcium phosphate. The monocalcium phosphate can be dissolved in water, and hence is the form known as "soluble phosphoric acid." The dicalcium phosphate is known under the name of "reverted phosphoric acid," for reasons which will be given later. Taken together, the phosphoric acid of the monocalcium and the dicalcium phosphates constitutes the available phosphoric acid of a superphosphate.

The problem, then, to the manufacturer of a superphosphate is to change the insoluble tricalcium phosphate into the soluble mono- and dicalcium phosphates. This is accomplished by the use of sulfuric acid and water.

The bones or rocks are ground before being subjected to the action of the acid, in order that the acid may reach all parts of the mass. In the changes which take place, one part of tricalcium phosphate is acted upon by two parts of sulfuric acid, yielding one part of monocalcium phosphate and two parts of calcium sulfate or gypsum. This is brought about by two parts of the element calcium in the tricalcium phosphate leaving their combination with phosphoric acid and combining with the sulfuric acid. The place of each of these parts of calcium (Ca) is taken by two parts of the element hydrogen (H) from the sulfuric acid, thus bringing together the elements of water (H_2O) in

the monocalcium phosphate. The reaction is represented by the following equation (H_2SO_4 representing sulfuric acid):

$$\left.\begin{array}{l}CaO\\CaO\\CaO\end{array}\right\} P_2O_5 + \begin{array}{l}H_2SO_4\\H_2SO_4\end{array} \quad \left.\begin{array}{l}CaO\\H_2O\\H_2O\end{array}\right\} P_2O_5 + \begin{array}{l}CaSO_4\\CaSO_4\end{array}$$

This is the ideal reaction to be effected, because it changes all of the phosphoric acid into a soluble condition. It is not possible, ordinarily, in practice, however, to bring this about. There is some part of the bones or rock which is acted upon by the acid in the proportion of one part of tricalcium phosphate to one part of the acid. This may be represented by the equation:

$$\left.\begin{array}{l}CaO\\CaO\\CaO\end{array}\right\} P_2O_5 + H_2SO_4 \quad \left.\begin{array}{l}CaO\\CaO\\H_2O\end{array}\right\} P_2O_5 \cdot CaSO_4$$

There is still another portion of the tricalcium phosphate which entirely escapes the action of the sulfuric acid. Hence there are always found in a superphosphate the three conditions of phosphoric acid: *i. e.*, monocalcium phosphate, or soluble phosphoric acid; dicalcium phosphate, or reverted phosphoric acid; and tricalcium phosphate, or insoluble phosphoric acid.

Dicalcium phosphate is called reverted phosphoric acid because, when monocalcium phosphate comes in contact with lime, it reunites with one part of lime, and forms the dicalcium phosphate; that is, the phosphoric acid reverts to a less soluble condition. If an

abundance of lime be present, two parts reunite with the monocalcium phosphate to form the tricalcium phosphate; thus the phosphoric acid may go back to its original condition; that is, it may become reunited with three parts of lime. However, the phosphoric acid in this tricalcium phosphate may be more available than in untreated tricalcium phosphate, because it is more finely divided, and may be more intimately mixed with the soil. The process of reversion is the opposite of that which takes place in the process of manufacture.

The lime that is taken from tricalcium phosphate by the sulfuric acid unites with the sulfuric acid to form gypsum, or land plaster. Hence, whenever sulfuric acid is used in the manufacture of a superphosphate, gypsum is always one of the constituents formed. (For further discussion of this subject, see Appendix B.)

CHAPTER XIII.

LIME AND VARIOUS AMENDMENTS.

THERE are various substances which are beneficial to the land at times, even though they add neither humus nor important quantities of plant-food. The benefits arise from various secondary actions which these substances have upon the land, such as improving its physical condition or texture, setting free plant-food, or conserving or collecting moisture. This class of substances is known under the general name of amendments. Some of them, like muck and similar substances, contain much directly available plant-food, but for the most part these materials are more useful for their secondary or incidental effects than for their intrinsic qualities.

LIME.

Lime is obtained from limestone rock, chalk and shells. These in their natural condition the chemist terms carbonate of lime ($CaCO_3$). By subjecting them to a strong heat for some time, the carbonic acid gas and moisture are driven off, and the product is quicklime, or caustic lime (CaO). When slaked with water, hydrate of lime ($Ca[OH]_2$) is formed. The carbonate of lime is usually found associated with

impurities, as with sand, and these impurities may be so abundant as to seriously reduce its value for agricultural and mechanical uses.

Who first discovered the agricultural value of lime is not known. Its general use for building purposes antedates mediæval history, and it could not have been long in use in the trades before its beneficial action on the soil must have been discovered by accident, if in no other way. Liming land was practiced to a limited extent before the Christian era. Soon after 1785, a time when many improved methods and improved breeds of domestic animals had their beginnings in Great Britain, the practice of liming the land became common in some localities.* In both England and Scotland the application of occasional large dressings of lime, 100 to 300 bushels per acre, became common by the end of the eighteenth century. The lack of thorough drainage, the growth of abundant vegetation and the absence of sunshine and warmth in England resulted in filling the land with partially decayed organic matter, and all combined to make the soil heavy and acid. Since drainage by means of underground conduits has become common in Great Britain, the practice of liming has been abandoned in many cases, and where it is still kept up much smaller applications are found to produce the best results.

Lime is one of the oldest and most common

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* A book upon the liming of land appeared in Boston in 1799. This was an American edition of James Anderson's "Essay on Quicklime, as a Cement and as a Manure."—L. H. B.

amendments or indirect fertilizers in some localities, but at least 99 per cent of the arable land in the United States has never been limed, nor is it likely to be in the near future. The virgin soil usually contains an abundance of available nutrients. The loose texture of the soil, the dry climate and cloudless skies, so common west of the Mississippi River, all tend to promote nitrification and to prevent acidity; hence, as the country becomes older, there is likely to be a lack of vegetable mold or undecomposed organic matter, and the planting of cover crops is likely to precede liming.

In all this vast territory, embracing more than one-third of the arable land of the United States, the price of lime has been so great as to preclude its use on lands even where the limestone and the land to be treated were in juxtaposition. In other cases, the cost of transportation equaled or exceeded the first cost of the lime. On the friable, fertile soils of the prairies the plow liberated year by year all the nourishment which the crops required. Thus it will be seen that the conditions in many districts of the United States have precluded the use of lime in agriculture.

When first removed from the kiln, lime weighs about 75 pounds* to the heaped bushel; that from shells weighs less than that from limestone. A ton of limestone converted into caustic lime (CaO) weighs between 1,100 and 1,200 pounds; hence it is econ-

* Seventy-five pounds of stone lime and 50 pounds of air-slaked lime are sold for a bushel at the kilns at Union Springs, N. Y.

U

omy to burn the lime near where the stones are quarried, since it weighs but three-fifths as much as limestone. In slaking, lime takes up considerable quantities of water; hence a ton of slaked or hydrated lime contains really but three-fourths as much lime as a ton unslaked. A heaped bushel of unslaked lime makes one and one-half bushels of slaked lime; therefore, it should be transported before it is slaked. When caustic lime is exposed to the air for some time it absorbs moisture and carbonic acid from the atmosphere, and becomes air-slaked or carbonate of lime ($CaCO_3$), or limestone. It is now in the form of a fine powder, much finer than ground limestone, and is of some value as an indirect fertilizer, and furnishes plant-food when applied to soils which are deficient in lime. Old pastures and sandy soils frequently respond to a dressing of air-slaked lime, but in most cases it is far better to purchase caustic lime, and by adding water convert it into the hydrate of lime, which acts more energetically than air-slaked lime does.

Recently hydrated, or "biting" lime, applied to sandy soil roughens it; that is, it acts upon the particles of which the soil is composed, thereby liberating the mineral matter. Gradually the lime passes downward to the bottom of the furrow, where it may become bound up with some of the liberated mineral matter and the finer particles of earth, and forms a hard-pan of greater or less tenacity, which arrests the too free passage of water downward. All of these complex actions improve sandy soils. When

soils naturally have a superabundance of lime, similar action may take place to such an extent as to form what is known as "lime-pan," which may be nearly impervious to water, and hence detrimental. Nitrification usually goes on too rapidly in light soils, and hence the humus is depleted and the power to hold moisture weakened, and therefore lime is not usually applied to sandy soils, as it is to clay, to hasten nitrification. The beneficial effects of lime in arresting the too free passage of water in sandy soils should not be destroyed by plowing at different depths, and hence care should be taken to assist the formation of a solidified sub-stratum by continuously plowing at the same depth, thereby securing the beneficial action which results from the trampling of the horses and the pressure of the plow on the bottom of the furrow. (See page 77.)

Recent experiments have thrown much light on the effects of liming land, yet lime acts in such a variety of ways, and produces such complex changes, that a wide field is still open to the investigator. It is known that in rare cases it may furnish needed plant-food, that it constitutes from 1 to 50 per cent of the ash of plants, and that it helps to bring about physical, chemical and biological changes in the soil. When applied to clay soils, it binds the fine particles together, or flocculates them. This results in opening channels which augment friability and porosity, and produces conditions which allow the freer passage of water downwards, and of moisture upwards by capillarity; air and heat are allowed

freer passage into and through the land, the cost of plowing is diminished, locked up mineral matter liberated, nitrification promoted, and a more comfortable environment is secured for plant roots.

Caustic lime decomposes certain mineral compounds, especially those containing potash, and makes them available; that is, changes potential into actual plant-food. It also corrects acidity, and in doing so unfits the soil for the growth of many coarse and undesirable plants, while greatly improving the conditions necessary for the growth of most of the higher and more useful kinds of plants. Lime acts chemically on the soil in many ways not well ununderstood, but its power to form useful compounds, such as hydrated silicates, is proved beyond a doubt. It is believed that some, if not most, of the available mineral fertilizing matter in the soil is held in the form of hydrated silicates. If this be so, additional light is thrown on the beneficial action of lime and some other substances.

Caustic lime acts energetically on the organic matter in the soil; hence beneficial effects may be expected when it is applied to peaty or other soils having a superabundance of undecomposed vegetable matter. Clayey soils, because of their tendency to remain cold, moist and compact, tend to become sour, and the plant-food which they contain is inert. All this produces uncomfortable conditions for the better plants, unless an unusual amount of labor is expended in fitting the soil. An application of caustic lime may change for the better, in

a marked degree, many or all of these undesirable conditions. Since clayey lands are usually too compact at the bottom of the furrow, it is well to plow at varying depths, shallow in spring and deep in the summer and fall, that the tendency to form a hard-pan, due to liberal applications of lime, the pressure of the plow and the tramping of the horses' feet at the bottom of the furrow, may be largely overcome. Dead plants or other organic matter can serve as plant-food only when they are decomposed, and the albuminoids changed into other nitrogen-forms and the mineral matter re-mineralized, or so far parted from its associates as to be acceptable to growing plants.

Liming land usually accelerates nitrification and fermentation. It may correct acidity and produce alkalinity, but if the alkalinity is too great,* fermentation and decay decrease. Usually lime is applied to the land or manure in such small quantities as to hasten instead of retard fermentation and nitrification. Most manures are injured when treated with lime, as ammonia is likely to be driven off, but it may be used advantageously to hasten the rotting of coarse manures, such as are composed largely of straw and maize stalks, if they are piled in layers with lime between, and the mass thoroughly wetted and covered with earth. Liming land, especially that which contains much organic matter, and that which is over-damp, tends to prevent rust and smut, and malformation of the roots of turnips, beets and similar crops. On the other hand, an ap-

plication of lime in any form is believed to promote the scab of potatoes. In some experiments, conducted at Cornell in 1896, to determine the amounts of soil moisture conserved or lost, the workmen remarked that one plat was "mealy," and did not crust over, as the others did. The plat referred to proved to be the one that had been limed. So far, experiments show that lime does not kill wireworms, slugs and beetles, but it may so change the character of the soil as to induce them to find more congenial conditions.

Lime should be removed from the kiln soon after it is burned, and placed in convenient piles on the field where it is to be spread. If a slight depression is made and the ground smoothed, and from three to five bushels are thrown in a pile and the mass covered with earth, it will slake in a few days if the ground is moist, but if dry some water should be added before it is covered. If slaked quickly by a large addition of water, the mass does not break up into as fine a powder as when slaked slowly, with the air largely excluded. Therefore, to secure the best and cheapest results, the slaking should proceed only moderately fast and in the presence of as little air as possible. Lime for plastering-mortar is prepared by placing it in a slaking box and submerging in water. The milk of lime produced is then drawn off, mixed with enough sand to form a stiff paste, which is piled up and left from two to four weeks, that all the particles may be fully slaked, otherwise they may slake in the wall and

produce "smallpox pits." It will be seen that by this method the air is largely excluded from the lime until it is used, thereby preserving its caustic and binding or flocculating qualities. Air-slaked lime does not make good mortar, neither does it act energetically on the soil, since it is in its mild, not caustic, state.

What has been said about slaking lime intended for mortar, is to emphasize the need of excluding air, so far as possible, when slaking lime for agricultural purposes, and until it is applied to the land. If it can be applied to and incorporated with the fresh-turned surface soil, in the caustic state, it will be far more efficient than when applied in the mild, or air-slaked condition. True, this hydrated or "biting" lime ($Ca[OH]_2$), will become mild lime ($CaCO_3$), but before fully reaching this stage it will have acted beneficially and energetically, and when it has reached that state it will have lost none of its usefulness as mild lime.

Lime properly slaked is difficult to handle and spread, as it runs with nearly the facility of water. The earth covering, mixed with the lime, tends to overcome this difficulty. If the mixed material is thrown onto a stone-boat or sled it can be spread, with the wind, satisfactorily. Since lime tends to sink into the soil, it is best applied on plowed and partially fitted land, and then thoroughly incorporated by surface tillage. On permanent grass lands, for various reasons, it is best applied in the fall. It may be predicted with some degree of accuracy where lime

is likely to be most beneficial; viz., on sour, peaty soils, and those having large amounts of undecomposed vegetable matter; on heavy or clayey lands, in conjunction with barn manures and other coarse organic substances; and on sandy lands, if in conjunction with a system of green manuring. The old saying that "liming the land makes the fathers rich but the sons poor," has a grain of truth in it, for lime may easily be made to deplete the soil of humus, and even mineral constituents, to the point at which it no longer produces profitable harvests; but, when judiciously used, in conjunction with crude organic matter, it is often one of the cheapest of the indirect fertilizers, as it serves to liberate plant-food which without it would long remain useless.

Wherever lime can be secured cheaply, from 10 to 15 cents per bushel, it should be used at the rate of from 20 to 40 bushels per acre in a small way at first, and the results most carefully noted; for only by actual application can it be certainly known whether or not it will pay. Theorizing may be good, analyses of the soil better, but the way to solve all such problems is to put clean-cut questions to the land and the plants which grow upon it, and while listening to the answers, note the points which have been settled by the chemist and the experimenter, that additional light may be thrown upon what is seen, or appears to be seen. The chemist in the laboratory and the farmer in the field must work together in the future.

LIMING TO CORRECT ACIDITY OF THE SOIL.

No recent experiments with lime have attracted more attention than those made at the Rhode Island Station,* and since they are destined to be far-reaching in their results, it is a pleasure to quote them freely. Of necessity, but brief extracts can be made, yet it is hoped that the student will become sufficiently interested to read the full text of the publication. The facts reached are doubly valuable, since they give the results secured in both field and laboratory, and the only regret is that space does not permit making fuller and more connected quotations.

"So far as we have been able to ascertain, no one in this country has thus far definitely called attention to the existence of an injurious degree of acidity in uplands or naturally well-drained soils, and at the same time pointed out a simple and practical means for its recognition. American agricultural chemists appear not only to have been of the opinion that an injurious degree of soil acidity is to be found only in muck and peat swamps, and in spots where stagnant water occurs, but they make no mention of making tests for acidity as a means of recognizing a deficiency of carbonate of lime."

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"E. W. Hilgard,† in the course of his work upon

*"The Acidity of Uplands Soils" by H. J. Wheeler, B. L. Hartwell and J. M. Tucker; being a portion of the Eighth Annual Report of the Rhode Island Agricultural Experiment Station. 1895.

†Tenth United States Census.

the soils of the southern states, particularly in connection with the sandy pine lands of Mississippi, has called attention to their need of lime, though we find no mention of tests for acidity having been made in connection therewith; he states, however, in a private communication, that the recognition of their acidity was what led to his recommendation of the application of this substance. He furthermore says: 'You are doubtless right in thinking that attention should be more definitely called to the importance of soil acidity as an unfavorable agent in agriculture outside of swamp or marsh lands.' A. Voelcker* says that 'There is a ready test for ascertaining whether a soil is likely to contain an injurious constituent. All that is necessary is to put a strip of litmus in contact with wet soil; if the blue color of the test paper turns rapidly red, the soil is certain to contain something injurious to plant life.' The soils which he appears particularly to have examined were reclaimed marshes, muck, etc., or what would be termed unusual soils. Several French writers† refer to the acid soils of Brittany, Limousin, and other sections, which in many instances have been wonderfully benefited by the use of lime. Many of the soils referred to appear to have been upland, or well drained. Schultz-Lupitz,‡ in speaking of the sandy soil of his section, in Ger-

*Journal Royal Agricultural Society, England, 1865, p. 115.

† See particularly Müntz and Girard, Les Engrais, tome 3, Paris, 1891, pp. 190, 191.

‡ Die Kalidungung auf leichtem Boden. Berlin, 1890, s. 25.

many, refers to its being poor in lime, and, therefore, becoming sour and unfit for the economical production of plants; he makes, however, no reference to the use of litmus paper nor of any other means of definitely ascertaining its acidity, but appears to infer that it was acid from the beneficial action of lime upon it. E. W. Hilgard says:* '"Saurer Sandboden"† is the expression I have frequently heard applied in Berlin to the uplands of that region and the Mark Brandenburg at large.' W. Detmar‡ states distinctly that not all soils which are excessively rich in humus are acid, and, on the contrary, that sandy soils sometimes give an acid reaction; and he mentions in the same connection the value of the litmus paper test as an indicator of this condition. Th. Hubener§ likewise calls attention to the frequent acidity of sandy soils.

"S. W. Johnson‖ states that 'a soil that is fit for agricultural purposes contains little or no free acid except carbonic acid, and oftentimes gives an alkaline reaction with test papers,' while Storer¶ asserts that 'cultivated soils, though sometimes neutral to test papers, as a rule exhibit a faint acid reaction; and experience with water culture has shown that slightly acid solutions are favorable for

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*Quoted from a private communication by permission.

† Sour, sandy soil.

‡ Die Landw. Versuchs-Stationen, 14, s. 277.

§ Schultze's Lehrbuch der Chemie für Landwirthe, Vierte Auflage, s. 588.

‖ How Crops Feed, p. 229.

¶ Agriculture, vol. ii., p. 148.

the growth of plants. But any excess of soluble acids in the soil would be highly detrimental.' Jas. F. W. Johnston,* in speaking of soils which are moist and where much vegetable matter abounds, says that 'the effect of this superabundance of acid matter is, on the one hand, to arrest the further natural decay of the organic matter, and, on the other, to render the soil unfavorable to the healthy growth of young or tender plants.' Voelcker† says regarding the action of soil upon litmus paper: 'If the blue color of the test paper turns rapidly red, the soil is certain to contain something injurious to plant life. All good and fertile soils either have no effect upon red or blue litmus paper, or show a slight alkaline reaction; that is to say, in a wet condition they restore the blue color to reddened litmus paper.' A. Mayer‡ states that the so-called sour humus is really somewhat sour, and that on this account is, without doubt, injurious to plants. Shultz-Lupitz, as heretofore cited, speaks of sandy soils becoming sour and unfit for the profitable production of plants. Mulder§ claims that 'a good soil should turn a red litmus paper blue' (that is, it should be alkaline, and not acid). A. Stutzer|| says that 'a large amount of acid in soils is injurious to all cul-

* Lectures on the Application of Chemistry and Geology to Agriculture, New York, p. 403.

† A. Voelcker, Jour. Royal Agricultural Society, England, 1865, p. 115.

‡ Lehrbuch der Agrikulturchemie. Heidelberg, 1886, s. 289.

§ Chemie der Ackerkrume Bd. 1. s. 363, 364.

|| Leitfaden der Dungerlehre, Vierte Auflage, s. 78.

tivated plants.' Th. Hubener* states that 'hardly anything has so great an influence upon the character of the vegetation as the condition of the humus.' In this respect plants may be divided into three classes: one which thrives best where the humus is sour, another which refuses to grow where sour humus is present, and a third and the largest class, the individuals of which can accommodate themselves to either condition; and also that where a soil is recognized by means of litmus paper as being sour, the acidity must be overcome by the use of marl or lime. * * * *

"Certain cultivated plants have been found to nearly or quite succumb until lime has been applied, after which they have made a magnificent growth; characteristic among these may be mentioned common red clover, spinach, lettuce, beets and timothy (*Phleum pratense*). Upon our soil, when left to itself for some time, certain plants seem eventually to predominate, while others gradually disappear. Considering that the soil contains no carbonate of lime, to the absence of which, together with other basic compounds, its acidity is apparently due, it will be obvious, in connection with what has been said above, that the natural vegetation would be of a type suited to such a soil. Having observed, therefore, what plants thrive here naturally, the recognition of similar plants elsewhere would lead to the natural conclusion that there similar conditions may also exist. Those plants which have appeared par-

* Schulze's Lehrbuch der Chemie für Landwirthe, Vierte Auflage, s. 588, 589.

ticularly characteristic of acid soil in our immediate vicinity are the following: Birdfoot violet (*Viola pedata*), wild or beard grass (*Andropogon scoparius*), species of St. John's-wort (*Hypericum*), common or soft rush (*Juncus effusus*), wood rush (*Luzula campestris*), and several mosses; the appearance of common sorrel (*Rumex Acetosella*) is common as soon as the soil is cultivated. In addition to one or two of the plants above mentioned, Ruffin speaks of the pine as a plant which thrives best upon soil poor in lime. Various French* and German writers state that clover fails to thrive upon land deficient in carbonate of lime, and, as above stated, we have found the same to be true of timothy; so that by observing not only those plants which thrive, but also those which fail to thrive, indirect evidence of the needs of the soil may be, in a measure, afforded. In the course of observations upon the nature of the wild plants, cultivated grasses and clover, not only in many parts of Rhode Island, but also in some parts of Massachusetts and Connecticut, the soil appears to be probably in somewhat the same condition as our own; quite marked changes in this respect are noticeable as one travels westward from Boston. At a distance of twenty or thirty miles, clover and timothy are, in certain sections, found to largely disappear, and farmers in such sections have stated that clover cannot be made to grow, and that timothy runs out quickly. In fact, statements to the same

*Müntz and Girard: Les Engrais, tome 3, p. 190; also Deherain: Traite de Chimie Agricole, 1892, p. 531.

effect have recently come to our notice from New York, Connecticut and several of the eastern seaboard states."

The Rhode Island report makes the following summary of the literature:

"The removal of plants from the soil, and the use of certain fertilizers, doubtless exhaust the lime and other basic ingredients of the soil more rapidly than would be the case were nature allowed to take her course.

"That an acid condition is liable to result, in consequence of the above-mentioned operations, particularly in the case of soils derived from rocks deficient in basic ingredients, we believe to be a reasonable assumption.

"While some plants, like clover, timothy and beets, appear to be injured by a lack of carbonate of lime or by the resulting acidity of the soil, others appear to thrive best under such conditions.

"A strongly marked reddening of blue litmus paper seems to be a simple and effective indication of the condition of a soil in the above-mentioned particulars.

"The value of a satisfactory method for determining the relative acidity of soils would seem to be great.

"A dangerous degree of acidity, or at least a fatal lack of carbonate of lime, appears to exist in upland and naturally well-drained soils, and is not confined to muck and peat swamps and very wet lands, as most American and many other writers seem to as-

sume, in view of which it appears that the test for acidity should be more generally applied to such soils.

"That this condition of upland soils has not been more fully recognized heretofore is not surprising, for the reason that the failure, or partial failure, of certain crops, has been attributed to winter-killing, poor germination of seeds, drought, excessive moisture, or attacks of insects or fungi. Upon soils where certain plants are injured only to a limited extent by acidity, others would be expected to thrive best of all, in consequence of which it is not surprising that the cause for the partial failure of certain crops upon them has not been suspected.

"The inefficiency of land plaster, as compared with air-slaked lime, in the culture of beets, and in overcoming the ill effect of sulfate of ammonia, as well as the highly beneficial results from the use of caustic magnesia and carbonate of soda, all tend to further strengthen the position that the fault of the soil in question is a lack of basic ingredients, to which the presence of noxious compounds, which may partly or wholly give rise to the acid reaction, is attributable."

By the courtesy of Professor H. J. Wheeler, of the Rhode Island Station, I am permitted to make extracts from a paper recently read by him at Washington:*

"Soon after the establishment of the Experiment Station, at Kingston, R. I., it became noticeable that

*"The Recognition of the Acidity of Upland Soils as an Indication of their Need of Calcium Carbonate." Read before the Association of American Agricultural Colleges and Experiment Stations, November 11, 1896.

the farmers, at least in the southern portion of the state, grew but little if any clover, and upon inquiry among them, it was stated that it could not be grown, owing to the fact that it winter-killed. The only place where clover could be seen to any extent was in a few fields near stables and upon an occasional farm where wood ashes had previously been used. Timothy failed to endure for more than one or two years, while red top and Rhode Island bent were the two grasses most universally found. On seeding land upon the college farm with clover and mixed grass seed, it was found to be practically impossible to secure a stand of timothy and clover, though a fair crop of Rhode Island bent and red top could be obtained. It was observed that with an increased application of ammonium sulfate, the crop of Indian corn was lessened instead of increased, and where the full ration of nitrogen in this form was used, the yield was much less than on an adjacent plat treated the same in other respects, but where nitrogen was not applied. This condition has continued uninterruptedly up to the present time.

"In searching for a cause for the ill effect of the ammonium sulfate, non-nitrification, and in consequence of a poisonous effect of the ammonium sulfate or of compounds produced by its reaction within the soil, were considered. All of the conditions essential to nitrification seemed to be right, provided the nitrifying organisms were present, unless perhaps the difficulty was due to an unusual acidity or alkalinity of the soil, which reaction was already

well known to exert a marked influence upon nitrification in various media. An examination of the soil by means of blue litmus paper revealed the fact that it was decidedly acid. In consequence, the idea of the use of lime naturally suggested itself.

"In recognition of the writings of American agricultural chemists, in which they note the effect of sourness upon the growth of plants in lowlands or wet meadows, as well as those of European writers, some of whom do not confine their references to swamp lands exclusively, and to lowlands naturally wet, the idea suggested itself that the acidity of the upland soil at Kingston might be sufficient to exert a marked influence upon the growth of various agricultural plants. Accordingly, in 1893 an experiment was begun which has been continued since without intermission, in which nearly 150 different varieties of plants have been tested in this particular. In order to eliminate in this experiment, so far as possible, the influence of the acidity of the soil upon nitrification, sodium nitrate was employed upon two plats in connection with muriate of potash and dissolved boneblack, one of the plats receiving an additional application of air-slaked lime. In the course of this experiment, some of the most striking differences, not only in members of the same family of plants, but also even in species belonging to the same genus, have been observed. When fresh applications of lime had been made rye was benefited little, if at all, and sometimes apparently injured, while oats showed a slight benefit, wheat a very marked one, and barley

even more than wheat. Serradella, lupines and one or two other leguminous plants have been invariably injured by liming, while red clover, peas and certain others have been benefited decidedly thereby. One of the most remarkable instances is that of watermelons and muskmelons. The former in two trials were injured by liming, and in the second trial in a most serious degree; while the latter were a total failure where lime was not applied." * * * *

"In the course of these experiments it has been found that calcium sulfate does not prevent the ill effect of ammonium sulfate, while air-slaked lime does it effectually. Magnesium sulfate fails likewise, while caustic magnesia is highly effectual."

* * * * * * * * *

"From the foregoing it will be seen that there is great probability that the larger portion of the state of Rhode Island is suffering from a deficiency of carbonate of lime, a fact which in many instances would not have been surmised from a determination of calcium oxid in a hydrochloric acid extract of the soil, for in the soil of the Experiment Station at Kingston there was found upon the hill, by this method, .45 per cent of calcium oxid, and upon the plain .57 per cent, in both of which cases one would have been disinclined to believe that such a serious deficiency of carbonate of lime existed. In one experiment at the Rhode Island Experiment Station, gypsum was applied at such a rate that the equivalent of .2 per cent of calcium oxid was present in the soil, yet without overcoming the ill effect

of ammonium sulfate. In another experiment, gypsum representing about .13 per cent of calcium oxid failed to have the same beneficial effect upon the growth of beets and barley as an equivalent amount in form of air-slaked lime. It must be obvious, therefore, that in certain instances soils may contain even a high percentage of lime, all of which may be in such combination within the soil that an acid reaction is possible, whereby plants are injured, even if nitrates are supplied, in which case calcium carbonate or other alkaline agents are efficient remedies It will be seen, furthermore, that where such soil-conditions exist, a test for acidity gives a better indication of the needs of the soil in respect to lime than an analysis of the hydrochloric acid extract, and in view of the fact that many soils, not only in Rhode Island, but some also from Connecticut, Massachusetts, New York, Virginia and other states, have been tested in our laboratory and found acid, and in view of the actual demonstration of the value of lime in the culture of beets in various parts of Rhode Island, it must be obvious that agricultural chemists should give more attention to this important factor in their examinations of soils. Most of the soils upon which lime has proved so beneficial in connection with the culture of beets, and several where clover has likewise been benefited in a most wonderful manner, belong essentially to that group of soils which would be considered as upland and naturally well drained, and would not be classed, under any circumstances, as naturally wet, or be spoken of as

'swamps' or 'morasses.' It will be seen, therefore, that the question of the occurrence of acidity in upland or naturally well-drained soils, even though it is

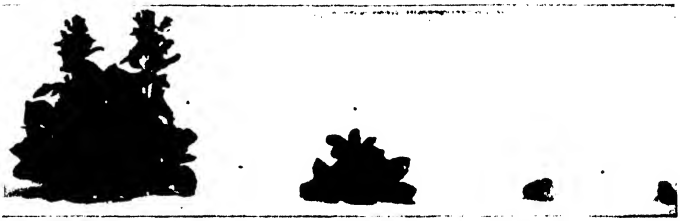

Fig. 40. Experiments with lettuce upon acid soils.

almost unmentioned by American agricultural writers as a matter of importance, is deserving, in certain sections of this country, of perhaps even more attention than it has received in Europe."

In order to still further emphasize the importance of these experiments in correcting the acidity of the soil, four pictures of comparative yields are taken

Fig. 41. Red table beets grown respectively with lime, gypsum, and no alkali.

from the Eighth Annual Report of the Rhode Island Station. Fig. 40 shows yields with lettuce. The two plants at the left are representatives of plats which

received sodium carbonate, the end one a full ration and the second one a half ration. Plats (represented at the right) which had no sodium carbonate

Fig. 42. Sugar beets treated like those in Fig. 41.

produced no plants. Fig. 41 shows comparative yields of red table beets. The two piles at the right received no lime; those in the middle received land plaster; and the two piles at the left had air-slaked lime. Fig. 42 is illustrative of the yields of sugar

Fig. 43. Mangolds without and with lime.

beets, the treatment being in the same sequence as in Fig. 41. Fig. 43 shows mangolds. The pile at the right was from a limed plat, and that at the left from

an unlimed plat. Both also received muriate of potash, dissolved bone-black and nitrate of soda.

GYPSUM, OR LAND PLASTER.

The practice of sowing small quantities of gypsum, or sulfate of lime ($CaSO_4$) on clover fields soon after the plants start in the spring, and on maize and potatoes when a few inches high, was common in many localities in the United States wherever the fields were within easy reach of the plaster beds, from about 1835 to 1865, since which time its use has been largely abandoned. In early days the application of one or at most two bushels per acre on clover not infrequently resulted in increasing the yield of hay from 20 to 50 per cent. As time passed, it was observed that gypsum failed to produce the old-time results. At first it was supposed that the quality of the gypsum had deteriorated, but a few experiments with that of known composition showed that the trouble was not all due to the poor quality of the material, though some of the gypsum on the market gave evidence of not being up to a high standard, as is shown by the following table of analyses made by Professor G. C. Caldwell, Cornell University, 1879. He precedes the table with the following explanatory note:

"Ordinary plaster, as used for agricultural purposes, owes its value to the sulfate of lime that it contains, and which, in the following table, is designated as pure plaster; the other ingredients are

chiefly carbonate of lime and entirely worthless insoluble matters."

Locality.	By whom sampled.	Insoluble matter.	Pure plaster.
Nova Scotia.	Station.	.76	96.9
Clockville, N. Y.	Canastota Farmers' Club.	8.62	66.78
Chittenango, N. Y.	" " "	6.08	82.49
Cottons, N. Y.	" " "	13.04	67.5
Wampsville, N. Y.	" " "	11.1	55.5
Fayetteville, N. Y.	" " "	7.58	77.25
Cayuga Beds, N. Y.		Undetermined.	72.67
Onondago County.		5.68	77.61
Onondago Co. Mills.	F. L. Kilburn.	Undetermined.	48.57
Springport Beds.	Dr. S. M. Babcock.	8.19	66.71

Gypsum is now used to some extent on the floors and roost platforms of hen houses, and on the floors of cow and horse stables, to fix the ammonia which tends to escape, and to dry and sweeten the stables. It is believed that this indirect way of reaching the plant is quite as satisfactory as the direct method, and that the valuable results reached in the barns nowise injures the effects which might be secured from a direct application. It requires 400 parts of water to dissolve one of gypsum; hence, an application of from one to two bushels per acre is likely to be as beneficial as a larger quantity. Gypsum should not be applied to growing potatoes or to land intended for growing them, for the same reason that lime is withheld; viz, a tendency to increase the disease known as scab.

Formerly it was believed that the marked beneficial results of a light application of gypsum, especially on clover and maize, were produced by the

action of the gypsum on the leaves and stems of the plants, enabling them to conserve moisture; that is, it prevented rapid transpiration from their surfaces, and hence carried the plants safely through periods of drought. Beneficial effects of gypsum could not be due to the lime which it contains, since the quantity applied is infinitesimal; 100 pounds, of the average composition of the ten samples given in the preceding tables, would contain but 26 pounds of lime. It is now believed that gypsum acts upon the double silicates, and liberates and makes available the potash which, in the absence of the gypsum, would be unavailable. It may also take up and fix small quantities of ammonia from the air. Bare soils treated with gypsum are found to contain more moisture in dry weather than those which are untreated. Whether it produces the result by conserving moisture, or by taking it from the atmosphere, or acts in both directions, is not certainly known. When arable soils have been depleted of a part of their potash, it may be better to apply potash than to set free the small amount remaining in the soil by the use of gypsum, especially when phosphates are used, for they contain a large percentage of gypsum, which is secured by treating insoluble phosphates with sulfuric acid; the latter unites with the lime and forms sulfate of lime, or gypsum. Therefore, whenever phosphates are used additional gypsum would be unnecessary.

In speaking of "Western and Central Prairie Soils," in Bulletin 30 of the Minnesota Agricul-

tural Experiment Station, page 173, Professor Snyder says:

"The indirect action of land plaster (gypsum) on these soils in liberating plant-food, particularly potash and phosphoric acid, is unusually marked. Experiments conducted in the laboratory have shown that small amounts of gypsum are quite active in rendering potash, phosphoric acid, and even nitrogen, soluble in the soil water. It is not the land plaster itself that furnishes the food, but it is the power that it possesses in making the mineral matters available that are already in the soil. Land plaster acts more as a stimulant and not as a direct fertilizer, and if not used to excess it will be a profitable fertilizer to use on these soils, especially to bring in grass and clover."

From what has been said, it will be seen why gypsum fails to produce the marked results it did when the soil contained large stores of potash which only needed to be liberated to become useful, and that by the use of phosphate or superphosphate a double benefit may be secured, as they may provide phosphoric acid directly and potash indirectly,—two necessary elements of plant growth. Whenever gypsum fails to produce marked beneficial results, it may be assumed that potash would be beneficial. Notwithstanding what has been said, the use of small quantities of gypsum about the henneries, stables and manure heaps should not be diminished, but rather increased.

The alkali soils so common west of the 115th me-

ridian may in many cases be successfully tilled if an application of gypsum is made. Deep plowing and frequent surface tillage may also be made to assist in reclaiming these lands. Professor E. W. Hilgard, of the Agricultural Experiment Station of the University of California, in his report in 1889, on the treatment of alkali soils which contain such large percentages of "black alkali" (carbonate of soda, or sal-soda), and also the less harmful "white alkali," or sodium sulfate, says: "The remedies suggested are largely based upon the diminution of surface evaporation, the prevention of the formation of surface crusts, and, in case of the presence of the most noxious ingredient, carbonate of soda, its neutralization by means of land plaster, which converts it into a harmless neutral salt." "The analyses having further shown the presence in most of the alkali salts of large supplies of *potash salts*, *soluble phosphates*, and *nitrates*, the high and lasting productiveness of the land when reclaimed has been placed beyond all cavil, and has, in numerous cases of intelligent treatment, been amply confirmed by experience."

The above emphasizes the fact that soils may contain an abundance of potential fertility, but fail to respond to superior tillage. In like manner many soils with no injurious carbonate of soda do not give full harvests, not for lack of potential fertility, but because some one or two factors necessary to full production are not seen, or are ignored.

The value of both salt and gypsum, when used on friable soils, for conserving moisture or for secur-

ing it from the air, has long been known, but no extended use has been made, at least not in this country, of a mixture of salt and gypsum, to the surface soil. Since plants too frequently suffer for lack of moisture during considerable periods in the summer months, it might be wise for the farmer to make applications of this mixture in a large way, since both gypsum and salt are inexpensive. The following table briefly sets forth the results of some investigations at Cornell:*

	Application per acre.	
Plat 1	300 lbs. gypsum. 300 " salt.	Excess of moisture in first 8 inches of Plat 1 over Plat 4, 12,903 pounds.
Plat 4 (adjoining) untreated.		

It is not always possible to select field plats of exactly uniform surface and subsoil texture or fertility, hence there is need of verifying plat experiments in pots filled with soil of uniform texture and composition. Unglazed 8-inch flower pots filled with 17 pounds each of loamy soil were placed in a greenhouse July 11. One pound of water was added to each pot July 20, 24 and 28, and 2 pounds on August 2, 8 and 11,—9 pounds in all to each pot. A determination of moisture on August 16 showed that the pot treated to half a pound of salt and gypsum contained 12.09 per cent moisture, while the untreated pot contained 6.01 per cent, or less than half as much.†

* Second Annual Report Cornell University Exp. Station, 1892-3.

† Unpublished experiments, Cornell University Exp. Station.

ASHES.

The value and composition of wood-ashes vary so much, owing to the kinds of wood from which they are produced, the intensity of the fire when the wood is burned, and the care used in storing them, that their agricultural value can never be known with any degree of accuracy without having them analyzed. Large amounts (such as car-load lots) are usually made up of many small lots purchased at the farms. These vary greatly, and as the various purchases are seldom thoroughly mixed, it is difficult to get a sample which fairly represents an average, and, therefore, in all cases, except where the ashes are uniform in character, they have to be purchased without a full knowledge of their composition.

Nevertheless, a knowledge of the composition of a large number of samples helps the purchaser to judge more correctly as to the value of unanalyzed ashes than he could without such knowledge, especially if something can be learned as to where and how they were produced.

The following tables are submitted, with the belief that they contain some value when studied by the intelligent reader:

TABLE LXXXIII.

Canada hard-wood ashes.

(Sold as such.)

Average of fifteen analyses made by various stations.

	Per cent.
Potash	6.17
Phosphoric acid	1.88

Various woods.

The following are the results of analyses made at various stations; in most cases but one determination was made:

	Phos. acid, per cent.	Potash, per cent.
Soft wood, taken after heavy rains..........	.64	3.02
" " " " " "	1.5	2.62
Pine " " " " "	.66	1.53
Spruce, from boiler furnace..................	1.4	4.39
Cedar ashes	1.91	5.09
Spruce, from boiler furnace	1.27	1.93
" " " "	1.47	5.2
" tan bark	1.41	2.1
Soft wood	1.78	4.65
Hard "	3.	8.46
" "	2.56	9.
Birch twigs less than 2 inches in diameter...	5.89	4.86
White ash	1.29	5.23
Maple and birch	2.42	7.35
" birch, beach, ash and elm............	1.96	8.41
" and birch............................	2.06	4.87
Mixed stove ashes	1.48	7.7
" heater "	1.28	8.69
Maple and birch	2.09	6.35
Florida hickory	4.4	2.84
Kentucky hickory............................	1.3	1.75
	41.8	106.04
Average	1.99	5.05

Wood ashes.

(Origin unknown.)

One hundred and three analyses by the Massachusetts Experiment Station give the following:

	Average, per cent.	Extreme range, per cent.
Phosphoric acid...........................	1.65	.5 to 3.
Potash....................................	5.3	2. " 10.

Forty-three analyses made by the Connecticut Station:

	Per cent.
Phosphoric acid	1.42
Potash	4.96
Average of both	1.53 5.13

The average of the 182 analyses given above is 5.26 per cent of potash and 1.65 per cent of phosphoric acid. Whatever value may be given to the above averages, the fact should not be forgotten that the variation in content and values in the various samples is great.

In respect to coal-ashes, it may be said that they have no value as plant-food. (See Appendix.) In rare cases they seem to exert some beneficial action upon the physical constitution of the soil, but, in general, it may be said that the best use which can be made of them is to put them on roads.

COTTON-SEED HULL ASHES.

In preparing cotton-seed for extracting the oil, the hulls or bran of the seed are removed. Some of them are burned as fuel under boilers, and some are fed to cattle. The composition of the ash of hulls is no more uniform than that of wood-ashes, as they are likely to be mixed with wood ashes of inferior quality, and other substances.

The average of six analyses made at the Connecticut Station is as follows:

	Per cent.	Value per ton.	Extreme range per cent.
Phosphoric acid............	9.58	$13.41	5. to 17.72
Potash.....................	22.95	20.65	10.38 " 32.79
		$34.06	

The average of ten analyses from the Massachusetts, Alabama and Arkansas Stations is as follows:

	Per cent.	Value per ton.	Average of both. Per cent.
Phosphoric acid	9.89	$13.85	9.73
Potash	23.36	20.12	22.65
		$33.97	

It will be seen that the percentages of potash and phosphoric acid vary as widely in cotton-seed hull ashes as in wood ashes. This is probably not due to adulteration, but to the kinds of fuel burned under the boilers in conjunction with the hulls. Frequently pine wood is used in part, and if reference is made to Table LXXXIII. it is seen that ashes from pine may contain not more than .66 per cent of phosphoric acid, and 1.53 per cent of potash. It is evident that if pine wood forms any considerable portion of the fuel used to supplement the hulls, the value of the resultant ashes will be materially reduced. The only safe way is to purchase ashes on a guaranteed analysis, since it is seen that one supply may be worth three times as much as another. Ashes of a good quality appear to improve the physical texture of the land, as well as to furnish valuable plant-food in a most acceptable form.

RIVER AND SWAMP MUD, AND PEAT.

Six analyses of river and swamp mud from various Stations give an average of :

	Per cent.
Water	69.2
Nitrogen	.32
Phosphoric acid	.11
Potash	.08

Eight analyses of peat from various Stations give an average of .67 per cent nitrogen. Three analyses from various Stations give an average of .21 per cent phosphoric acid, and .13 per cent potash. How much of the various substances were available is not stated.

If the above percentages of valuable constituents are compared with those given in Tables I. and II. (pages 12 and 14), it will be seen that the swamp muck and peat are not richer than the good soils, with the exception of the nitrogen in the peat, which, without doubt, is far less available than it is in good soil. Peat, if dried, may be used as an absorbent for liquid manure, not so much for its inherent value as for conserving the nitrogen in the manure, and for improving the condition of the stables.

MARL.

Twenty-two analyses of marl from Kentucky Station (character not specified) gave an average of:

	Per cent.
Phosphoric acid	.047
Potash	2.2
Lime	1.11

Three analyses from the Connecticut Station give an average of:

	Per cent.
Phosphoric acid	1.35
Potash	5.43

Twenty-four analyses from the Maryland Station:

	Per cent.	Extreme range. Per cent.
Phosphoric acid	.38	1. to 2.
Potash	1.39	2.5 " 3.

Seven analyses of fossil marl by the Kentucky Station:

	Per cent.
Phosphoric acid	.23
Potash	1.17

Six analyses of shell marl by the Kentucky Station:

	Per cent.
Phosphoric acid	.31
Potash	.59

The potential plant-food in marls is not readily available, and hence is of less value per unit than when contained in high-grade commercial fertilizers. Liberal applications of marl are usually beneficial, but its value per ton is so small that it can only be used near the beds where it is found.

MUCK.

Ten analyses of muck made by the Connecticut Station give an average of 62 per cent water and .63 per cent nitrogen. Ten analyses of partially dry muck from various stations give an average of:

	Per cent.
Water	27.78
Nitrogen	1.02
Phosphoric acid	.23

Five analyses from the Connecticut Station give an average of:

	Per cent.
Water	47.85
Nitrogen	.65
Phosphoric acid	.16

Seven samples from various Stations give an average of :

	Per cent.
Water	34.87
Nitrogen	1.
Phosphoric acid	.25
Potash	.39

It is probable that a large portion of the plant-food in muck is insoluble; if so, its value would be much less than at first glance might be supposed. However, muck is often a very excellent dressing for improving the physical condition of the soil, either to break up and loosen hard clays, or to increase the water-holding capacity and to lessen the leaching of light sands.

SALT.

Common salt, or chloride of sodium ($NaCl$), is seldom applied to the land, although it has long been known that it sometimes increases productiveness, promotes brightness and strength of straw of the cereals, when applied in moderate quantities on certain classes of soils, and acts in other ways which are not well understood. Its application has proved to be of no benefit, or positively harmful, quite as often as it has been beneficial.

Several species of herbivorous animals, when not

near the sea-coast, have a fondness for salt, which, if judiciously gratified, is beneficial to the animals, especially in the case of cows in milk. It improves their appetites, increases their flow of milk, and indirectly may facilitate the churning of cream. From this it would be natural to conclude that the plants are unable to secure enough salt to fully satisfy the animals which eat them, and that in many cases light applications of salt might be made to indirectly increase the growth of the plant, and therefore promote the welfare of the animal and the quantity and quality of its products.

Salt, applied at the rate of 200 to 300 pounds per acre, may also assist the soil in conserving moisture, and in securing moisture from the air. Certain it is that land treated with salt contains more moisture in dry weather than that which is untreated. The application of a mixture of equal parts of salt and gypsum darkens the soil, and by its action tends indirectly to furnish moisture near the surface for the use of plants.

A solution of salt may be made to conserve fertility in manure heaps, especially when too rapid decomposition is taking place, as is likely to occur when manures containing large amounts of coarse bedding and the voidings of horses are placed in large piles.

The use of salt to destroy wire-worms is often recommended. Extended experiments have shown that an application of some eight tons to the acre, which would be necessary to kill the wire-worms,

would be an amount so great as to destroy nearly all vegetation.*

It has been briefly shown how salt, lime and gypsum may, under certain conditions, be made to promote plant growth; just when and where these conditions may be present can be determined only by careful observation and experimentation. Now that all of these indirect fertilizers and amendments, conservers of fertility and moisture, have become cheap and abundant, the use of salt and lime at least should become more common, with the view of determining their usefulness in any given case, when used alone or in conjunction with other substances.

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* See Bull. 33, Cornell Exp. Sta.

NOTE.—The attention of the reader is again called to the term "value per ton," which term has been used here and in preceding chapters. When unmodified, the term is misleading, yet it appears to be the best that can be used. The plant food in crude and unconcentrated fertilizing materials is likely to be less available than in high-grade fertilizers. From 80 to 90 per cent of the valuable constituents of the latter, and only from 5 to 10 per cent, and even less, of the former, may be readily available. The determinations from which the above tables of muck and marl are made seldom give the condition or availability of their plant food, and, therefore, their true value is not known. Reliable conclusions can only be reached by carefully noting the cost of transportation and application, and the effect on the soil and crop.

CHAPTER XIV.

GREEN MANURES AND FALLOWS.

Having done what he can to improve the productive power of his farm by means of superior tillage, barn manures, fertilizers, and various amendments, the farmer will now inquire about the use of clover and the merits of fallowing. The subject of green manures is itself of sufficient importance for an entire volume. Therefore only the most cursory attention can be given here, and it is treated from the standpoint of the farmer rather than from that of the chemist.

CLOVERS.

In many sections of the United States the clovers may be made to add materially to the productive power of the soil. Their numerous broad leaves form a shade which prevents useless evaporation from the land. Most of them are superior digesters of tough plant-food; that is, they have the power of securing food where many other plants would languish for lack of nourishment and moisture. They break down readily, and quickly give to succeeding crops, and in an acceptable form, the materials of which they are composed.

Some of the clovers are able to secure much of their nourishment from the subsoil, although the total weight of roots found in the lower strata of soil is small compared with the amount found in the upper strata, as the nourishment secured from the subsoil goes largely to increase the size of the roots near the surface, and not to enlarging the deep-feeding roots. Fig. 45 is a drawing, from a photograph, of the root of a clover plant fifteen months old from the seed and 22 inches long. This plant grew in the heavy clay soil of a clover field with others of similar size and character. The side roots could not be preserved, as the plant had to be dug out with a pick, and the tap-root could not be preserved in its entirety because of the hardness of the clay and the smallness of the root. The common clovers get the greater part of their food within two feet of the surface, though they may feed at the depth of five or six feet in rare cases.

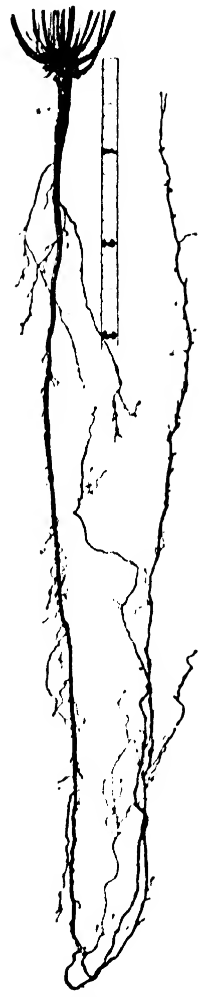

Fig. 45. Tap-root of a clover plant.

All the clovers tend to improve the physical conditions of the soil.

Those which have tap-roots also indirectly aërate the soil and improve drainage. They bring stores of potential nitrogen from the lower to the upper layers of the land, and also make positive additions of it to the soil. But if the resultant manure from feeding the hay secured from clover fields is not returned to the land, and no means are taken to supply mineral matter, the fertility, or productive capacity of the soil, will, in time, be greatly reduced. For illustration, consider a crop of 2.6 tons of red clover hay per acre, raised by the author on a fourteen-acre field last year. Assuming the average composition, the hay contained, in round numbers, 293 pounds of mineral matter, of which 101 pounds was potash, 30 pounds phosphoric acid, and 100 pounds lime. The hay also contained from 112 to 120 pounds of potential nitrogen. It will readily be seen that it would not take many crops of clover to so deplete the available mineral matter in the soil as to seriously reduce production, unless some were added. Superior tillage could prolong the period of full crops, but sooner or later mineral matter must be added, or loss would result. The wanton waste of manures has to a large extent counterbalanced the full benefits which should have been derived from the cultivation of clovers in many wheat districts. Additions of mineral matter to the land and increased clover culture are competent to speedily insure full crops and cure many ills which the land is heir to.

The following table gives in brief the results of

some investigations made by A. M. Bread,* at Cornell :

TABLE LXXXIV.

Composition of second-growth red clover cut in October, two years from seeding, slightly mixed with timothy.

	Lbs. per acre
Air-dried tops	5,417.
Nitrogen	91.5
Phosphoric acid	40.35
Potash	78.
Air-dried roots from 8 inches surface soil	2,368.
Nitrogen	47.36
Phosphoric acid	27.
Potash	31.96
Total of tops and roots	7,785.
Nitrogen	138.86
Phosphoric acid	67.35
Potash	109.96

Investigations made with clover one year from seeding, showed larger quantities of the three elements in roots and tops than two-year old clover did.

It is established beyond doubt that the clovers, especially the annuals and the biennials, are able to take large amounts of mineral matter from the soil, and they receive from the soil and air large amounts of nitrogen, which they store up in roots and tops. The proportion of roots to tops varies widely. The medium red clover, one year from seeding, gives a much larger proportion of roots to tops than clover two years from seeding. Red clover which produces two tons per acre may be expected to furnish po-

* Thesis for degree of Bachelor of Science in Agriculture, 1885.

tentially to the soil, after the first cutting, in roots and stubble, 40 to 60 pounds of nitrogen, 20 to 25 pounds of phosphoric acid, and 30 to 50 pounds of potash. Thirty bushels of wheat, or 1,800 pounds, and 2,700 pounds of straw, would remove approximately 46 pounds of nitrogen, 20 pounds of phosphoric acid and 26 pounds of potash. The chances are, then, that a clover stubble, if plowed early, might furnish of available plant-food two-thirds of the nitrogen, one-half of the phosphoric acid and two-thirds of the potash needed for a crop of 30 bushels of wheat per acre and the accompanying straw, if soil, climate and moisture performed their legitimate work. Although clover, both roots and tops, breaks down and decomposes rapidly, it could hardly be expected that all of the fertilizing constituents it contains would become available and be used by the wheat, or even by succeeding crops.

The amounts of plant-food which wheat, under present systems of tillage, secures from clover roots and stubble left in the soil have usually been exaggerated. The beneficial effects of clovers are due quite as much to their action on the physical condition of the soil as to the amount of available plant-food which they bring to the land. The species of clover which may give best results in any locality can be determined only by experimentation. In a warm climate the crimson clover does especially well; in the north the perennial species—medium, large red and alsike—are to be preferred, though in some localities crimson clover does well.

Recent results show that the large and medium red clovers, as orchard or stubble cover crops, are to be preferred to the crimson all along the debatable line where the latter does well only under favorable conditions. To receive the greatest good from clovers when used as cover crops, they should be sown early. Alfalfa may be made to produce much more forage than the clovers, but it is somewhat difficult to get the plant well started, and it is not at its best until it is from two to three years old, and when once well established, it is left undisturbed for several years. Hence, it tends to rob the land of its mineral elements, and does not bring to the land as much potential nitrogen as the clovers do, since the roots and stubble are utilized for their nitrogenous compounds only at long intervals. In a warm climate the cow pea and the crimson clover, if supplemented with potash and phosphoric acid, may be used not only to maintain the productivity of the land, but even to increase it, while diminishing the cost of tillage and improving the texture of the soil, thereby increasing its capacity for holding moisture.

Some garden plats, and even whole fields, are left to grow weeds in late summer and fall. These places would be better seeded to clover, peas or some other leguminous plants, since even a growth of two or three months serves to add humus and nitrogen to the soil. The following table sets forth the results of some experiments conducted in 1896 at the Cornell Experiment Station. Clover seeds were

sown August 1, and the plants were dug November 4, 1896, three months and four days after the seeds were sown:

TABLE LXXXV.

Nitrogen in an acre of clovers.

	Lbs. in top.	Lbs. in roots.	Lbs., total.
Crimson clover	125.28	30.66	155.94
Mammoth "	67.57	78.39	145.96
Medium red clover	63.11	40.25	103.36

The nitrogen in the clover may not be as quickly available as it is in cotton-seed meal; but, if so, it would usually be considered of less value per unit than that in the meal, the trade value of which is placed at 12 cents per pound. What part of the nitrogen of these clovers was secured from the air and what part from the soil is not known, but enough is revealed to indicate that leguminous cover and catch crops may be made to materially assist productivity.

A sample of the nodules from the roots of the above crimson clover was taken November 14, 1896. An analysis showed the following percentages of moisture and nitrogen:

	Per cent.
Moisture	79.37
Nitrogen	1.1

Not only leguminous plants, but others, as rye, wheat and oats, may be used to great advantage as cover crops, and all do well if sowed or drilled on unplowed land after inter-tilled crops. The red

clovers may be introduced into the pastures and mowed lands by sowing their seeds in early spring, after which the land should be harrowed and rolled. The harrowing and rolling will improve the grasses; and the clovers in time when their roots have decayed, will tend to aërate and drain the soil while furnishing acceptable nitrogen for the grasses. Since the clovers always benefit the pasture and hay grasses when associated with them, some care should be taken to keep at least a few such host plants in the grass fields at all times.

FALLOWS.

The practice of leaving the land fallow or uncropped for one or more seasons was common in ancient times. It was soon discovered that if the land was cultivated for all or part of the period of rest it was more fruitful than if left to be occupied by weeds and volunteer grasses. The first implements for tilling the land were so imperfect that the demands of the crops soon outran the available plant-food, and there were no better methods known for bringing the supply up to the demand than by weathering and by the growth and decay of vegetable matter. The French early discovered that "manœuvering" the land, that is, making the particles of earth change place by tillage, made it more productive. Fallowing at first was performed largely by spade and hoe on small areas; as civilization advanced and population increased, a larger, better and constant supply of food was needed, and,

as little manuring was practiced, summer-fallowing became common in all civilized countries. The effects of fallowing were easily seen and well understood, but the causes which produced the effects were often a mystery. It was noted that some crops were more benefited by fallowing than others. In England the fallow preceded the exacting wheat crop. In Italy, France and Germany, continuous tillage in the vineyards was found to be beneficial and took, in part, the place of the fallow. The practice of continuous tillage each season has become common in American vineyards and in Californian orchards, and might be more generally practiced with good results in the orchards of the east. Observing the wonderful results of clean and continuous tillage in orchards west of the Rocky Mountains, it is inexplicable that the practice has not become universal, for it not only sets free plant-food and conserves moisture, but adds to the fruitfulness of the trees.

About the beginning of the second half of the present century, great improvements were made in the plow and other farm implements, which enabled the farmer to till the land so much better than formerly that the practice of bare summer-fallowing has been largely abandoned. The result is that weeds, especially Canada thistles, are on the increase except where the most thorough intensified tillage has been practiced.

The benefits of summer-fallowing are so many that the practice should again come into vogue in many cases. The first plowing may be performed the last

of May (it should be deep and thorough), and immediately afterwards the surface should be put in fine tilth. This will induce most of the seeds in the soil to germinate at once, and then the young plants may be easily killed. As one of the chief objects of fallowing is to clean the land, this opportunity should not be allowed to pass without accomplishing the object sought. The character of the plowing, the weeds present, the sod turned under, and the soil, will determine whether it will be best to replow two or three times or to give deep surface tillage; the former is usually the safest and best when practicable. The last deep plowing should not be done later than the middle of August, if the land is to be planted to wheat or rye, that the soil may have time to solidify, the seed-bed, meantime, being kept mellow by shallow surface tillage. One deep plowing and a surface tillage may be made to accomplish all the desired objects in some cases. Bare summer-fallowing should clear the land of both perennial and annual weeds, change for the better the physical condition of the land, break up the hard-pan, facilitate the movement of moisture between the particles of earth, give time and opportunity to remove any obstructions to plow or harvester, and above all it should set free fertility, especially nitrogen. When any considerable amount of draining is to be done at one time, the opportunity to conduct a summer-fallow should be taken, as the injurious effects of tramping in early spring, the time when the draining would best be done, will be overcome by subsequent tillage.

Green summer fallows are those upon which plants are growing for the greater part of the time while the land is under treatment. They are frequently resorted to when the soil is light and poor, while bare fallowing is usually practiced when the soil contains a fair amount of plant-food, is weedy and of a clayey or tenacious nature. By plowing in August or September (in some localities even later), rye, crimson clover or other seeds may be sown and the plants plowed under when coming into head the following spring. Buckwheat, or better, peas in the north and cow peas in the south, may be sown on the fresh-turned earth early in the season. The cost of the seed, the climate, the land, and especially the resultant fertility, should all be considered in selecting a green manure crop to be grown preceding the fallow. Buckwheat furnishes a large amount of vegetable matter to plow under, grows readily on poor land, responds to even a light dressing of commercial fertilizer, leaves the land loose, and changes dormant into active plant-food, but is not a nitrogen gatherer. While peas and clover are quite as active in liberating food, they indirectly produce liberal quantities of fertility in the form of potential nitrogen. Wherever clover will succeed, it is by far the best green fallow plant, for a crop of hay may be taken off and yet leave the land more fertile than at first, for the stubble and roots contain a large amount of nitrogen, and some mineral matter is brought by the roots from the subsoil to the surface, as already explained. While a green fallow does not give so good an opportunity as a bare one

for setting free plant-food by tillage, or for destroying weeds, yet in one respect it is superior, for it actually adds vegetable mold and fertility to the land while setting free some of its dormant energies.

When neither of the above fallows is desirable, much may be done by a short fallow. If the land which has produced barley, oats or clover, be plowed immediately after the crop has been removed, some six or eight weeks intervene before seeding with fall grain or grass. This gives time for thorough surface tillage, and if the land is harrowed or cultivated every two weeks or oftener the results will be beneficial in many ways. This is the time of the year when nitrification goes on rapidly if the requisite moisture is present; and thorough tillage usually brings moisture to the surface by capillarity. Oats are not so good to precede wheat as barley is, as they ripen later, thereby shortening the period in which fertility may be set free by tillage and weathering. But this and other like crops may be shocked in rows, leaving wide intervals, which may be plowed and fitted as soon as the grain is cut. The time that elapses between the removal of one crop and the planting of another gives opportunity for liberating fertility by tillage and weathering, and, as little rain falls during this period, no loss of nitrogen by leaching will likely occur. Clover stubbles are sometimes left without plowing for two or three weeks after the hay has been removed, or until the new growth is several inches high. This is not always desirable, because dry weather later in

the season is likely to make the plowing more difficult, and less time is given for weathering, tilling and compacting the soil. Since the roots and stubble of the clover contain much potential nitrogen, frequently more than a crop of twenty-five bushels of wheat to the acre contains, it is best to plow early, or before the clover has made much growth.

The many opportunities which are present to most farmers for changing potential plant-food into that which is available, and for adding humus and nitrogenous compounds to the soil, are not fully utilized. Few persons fully realize what great benefits can be secured by a short fallow, or by plowing immediately after a crop has been removed, and starting another one, which may be plowed under or used as a forage crop later in the season. If nature's modes of action are observed closely, it will be seen that she attempts in every possible way, by means of hardy plants, and those which are able to maintain themselves on semi-sterile soils, to clothe the land with vegetation. Should we not learn a lesson from these natural soil-builders? Each plant and weed seems to find its appropriate soil and conditions, and crowds out those which are least adapted to accomplish the purposes desired. Many of these are simply digesters of tough plant-food in the surface soil or the subsoil; some of them, in addition, add greater or less stores of potential nitrogen to the surface soil.

He is a wise farmer who sees and appreciates that the silent forces, by timely direction and con-

trol, may be made to minister to his wants, and to change toil to healthful, inspiring, intelligent work. He is wiser who sees that the Great Designer intended man to have dominion over all things, and does not complain when he meets with partial failure, but sets himself at work to learn how he may command intelligently, that prompt and certain obedience may be secured.

CHAPTER XV.

ROTATIONS.

SINCE plants feed under ground, and, hence, out of sight, and since their food is largely invisible to the unaided eye, their likes and dislikes are not easily observed. An understanding of what kinds of food, and what proportion of them, plants thrive upon, is best secured, not by direct inspection, but by observing the effect of certain elements on growth, the proportion of one element to the other, their availability, and the quantity present in the soil. Other factors are always present demanding careful consideration,—the power of the plant to reach its food, the power of setting it free when it is reached, and the presence or absence of a suitable supply of moisture. Many and varied forces are always present, most of them acting silently and secretly. These forces and their action may be discovered by interrogating the plants, and by scientific experimentation. A knowledge of the wants of plants and of the causes that have produced the visible outward results is necessary to a good understanding of the laws which govern their growth.

Forty bushels of oats may be grown on land that will not produce fifteen bushels of wheat,

although the amount of plant-food required for the oats is greater than that required for the wheat; and this, too, where the soil and climate are adapted to grow both grains equally well. This happens, too, even if winter wheat has nearly twice as long a time as the oats has in which to secure its food. The proof is conclusive that, in this case, the oat plant has greater power than the wheat plant, either to reach its proper food or to set it free, or both.

Some plants require extra care when young, and do best when there is an abundance of food immediately at hand in the early stages of their growth,—as broom-corn, sorghum, and other slow-starting plants. Once well established, they are able to withstand hardships, such as drought and scarcity of food, much better than maize, which may begin its growth successfully under somewhat adverse conditions. Again, there are other plants which not only have the power to set free the mineral constituents of the soil in a marked degree, but they can also penetrate the subsoil for it, and can, moreover, through organisms attached to their roots, utilize the free nitrogen of the air. Among these are the clovers and other kinds of plants belonging to the leguminosæ, or pulse family. A notable instance of this may be seen on the dry, sandy plains of California, where the tree-lupine grows four or five feet in height in a most luxuriant way, while other plants utterly fail to maintain themselves. With its long tap-root, extending eight or ten feet below the surface,

reaching moisture and mineral food, and its independence of the soil for its supply of nitrogen, it can flourish where non-nitrogen gatherers cannot live. This plant should be named the "pioneer," for though not lovely or great in itself, it prepares the way for a variety of more useful vegetation. Plants vary as to the amount of food they require. The cacti of the desert and the pines of the abandoned fields of the south grow and flourish where better plants grow feebly or not at all.

The following figures give the amount of phosphoric acid and potash in a ton, air-dried, of a few common woods:

	Phos. acid, lbs.	Potash, lbs.
Old field pine	.14	.16
Ash wood	.24	2.98
White oak	.50	2.12
Hickory	1.16	2.76

Some plants get a large portion of their nourishment from the atmosphere. These being highly carbonaceous in their composition, require relatively little nourishment from the soil. Plants may be divided into two classes: those, as garden vegetables, which require the little earthy food they need easily available in the earlier stages of their growth, and those, as cereals, which fruit best if much of their earthy food is accessible just before or at blooming and seeding time.

Some plants start out in life with a greater reserve of nourishment to draw upon than others, and hence do not have to depend upon the soil until

they are well started in life. Cabbages, onions, and most grasses having small seeds begin their lives with a meager supply, and therefore an ample amount of available food near the seeds should be present when they germinate. On the other hand, some tuberous plants, as the potato, are able to grow for a considerable time and even fruit without any earthy nourishment except that contained within themselves.

Plants, like animals, vary greatly as to their ability to digest and assimilate the nourishment presented. Some, as buckwheat, rye, mullein, and even clover, and the old-field pine of the south, are able not merely to subsist, but to flourish, on soils in which the nitrogen and mineral matter are "tough," or not readily available. Among this class of plants are many of the weeds. Some are invigorated by a goodly supply of tender food, others, as the ox-eye daisy, are injured by it; and in fact there are several troublesome plants which succumb to liberal and persistent manuring.

With the feeding of animals it is comparatively easy to adjust the food to their respective wants, the milch cow thriving on soft, succulent foods, while horses kept for speed do best on hard, dry ones. Yet even in the feeding of animals, the equivalent of rotation is secured by making one animal subsist on what is refused by another. The colts relish the coarse stalks of clover hay which are rejected by the sheep, and swine grow on what is not digested by the fattening steers. The large mutton

breeds of sheep graze on the lowlands where the forage is coarse and succulent, and will lose flesh rapidly if forced to subsist on the short, dry grasses of the steep hillsides, while the merinos avoid the lowlands, prefering the arid, sparsely covered slopes. Similarly, a good bean crop can be raised on wheat stubble, though the land would fail to produce a second paying crop of wheat until it had been fertilized. While it is true that wheat may be and has been made to follow wheat, and maize to follow maize, for many years in succession with profit, yet in both cases, especially the former, unusually good preparation of the soil must be secured, or a very large amount of available plant-food, or that which can be made quickly available, must be carried by the soil, or a liberal amount of nourishment must be added each year. Either practice may be unnecessarily expensive and wasteful if climatic and other conditions will allow rotation to be practiced.

This short discussion, and the few illustrations of the habits, likings and powers of plants, are given in order to emphasize the need of noting most carefully the law or laws which govern the growth and fruiting of each species and variety of plants raised, that the highest success may be secured. While the wants of all plants are similar, yet no two species or even varieties have identically the same wants, or possess the same powers of supplying them from the soil. Hence, the exacting crops should be grown when the land is most fertile, and the least exacting crops when the land is least fertile.

SPECIFIC DIRECTIONS UPON ROTATIONS.

Up to the present time, but little attention has been given in America to the subject of rotation and to the economizing of fertility, because the virgin soil usually contains a wealth of fertility, and the husbandman is free to raise what finds the most ready sale or is the most easily transportable, or those species of plants whose needs and habits he knows best. This has frequently resulted in allowing many noxious weeds to get a firm foothold, in depleting the soil of certain elements while leaving a superabundance of others, in robbing the surface soil of the requisite amount of vegetable mold, in compacting the land to an undue extent, and in leaving the subsoil largely unused. In exceptional cases, as in the northwest, and in a few valleys, and on land frequently fertilized by overflow, it may not be merely expedient but even wise to ignore the laws of rotation for a time, and practice continuous cropping with one variety of plants, but sooner or later rotation must be resorted to if production is to continue to be profitable, unless the land is kept liberally fertilized.

Intelligent rotation can be made to accomplish many things that are not secured by the haphazard methods now almost universally employed in this country. If systematically carried on, it can be made to destroy a large number of troublesome plants, or to so reduce their vitality as to make them harmless. Consider, for instance, land infested with plantain or wild carrot. These plants fruit

after the medium variety of red clover is cut for hay. If land upon which winter wheat or rye is growing be seeded to clover with or without timothy, these weeds will not damage the grain crop nor seriously interfere with the early growth of the clover the following year, because they do not seed until midsummer. As soon as the clover is cut and removed they quickly throw up their seed-stalks, blossom and fruit, if not destroyed. True, a few weeks after haying the field may be mowed a second time to prevent the weeds from seeding, but enough always escape to reseed the land, and no permanent, beneficial results are secured. If, however, the clover stubble be thoroughly plowed immediately after the first cutting, the reseeding to weeds will be prevented. Then, too, this is the most suitable time for plowing the ground preparatory to sowing wheat or rye.

If a short, two-year rotation of wheat or rye and clover be pursued for a few years, the land will be nearly cleared of all of this class of weeds, provided that no seeds of the undesirable plants be sowed with the grain or grass seed, and none are carried to the field in manures; and the same practice will dispose of wire-worms and white grubs. Finally, a little hand-weeding will be required to make the work complete when wild carrots and similar plants are present. When the farm is overrun with weeds, it is impossible to keep the manure free from their seeds; therefore, only commercial fertilizers should be used on the fields under treatment.

This short rotation of wheat and clover not only

tends to clean the land, but also improves its physical condition, and conserves and adds nitrogen and humus to the soil. To preserve the productive power of the land, mineral fertilizers must be applied, or the cereals used in the rotation will fail to give the highest results, and weeds not before objectionable will assert themselves. This short rotation, or one similar to it, cannot be too highly recommended for destroying certain kinds of inferior plants, that rob and crowd out desirable ones, and cause the fertility of the land to be diverted into undesirable channels. When climate or other conditions make it undesirable to raise the winter cereals, the rotation may be modified by sowing to turnips or millet (preferably the former, in rows with inter-tillage), on the inverted and prepared clover stubble. If the land is fall-plowed after these crops are removed, the ground will then be ready to receive the spring cereal and the clover seed as soon as the land is workable.

Rotation may be made to increase production, while the land may receive at the most appropriate time its usual amount of manures. In some cases the wheat plant is injured by the liberal application of them. If the rotation is so managed as to apply the manures to some other crop in the rotation, as maize, the results in such cases may be far more satisfactory than when they are applied directly to the wheat land. A liberal application of farm manures every three or four years to land upon which clover is grown, supplies, under these conditions, relatively

too much nitrogen for the mineral elements they contain. If wheat is grown, the plants will be porous in structure, the straw and leaves too abundant, and lodging may ensue. If the same quantity and kind of manure be applied to maize, beneficial instead of detrimental results will be secured, and the unused residue from the manures will not be sufficient to injure the other cereal crops that may follow.

A four-year rotation may also be made to clean the land of some classes of noxious weeds, as, for example, the Canada thistle, and also to economize fertility. If the rotation is started by plowing a timothy or clover sod for maize, potatoes, or some other inter-tilled crop, these pests can be kept from breathing one entire season; that is, prevented from forming leaves, and they will either die or be so stunted that they will not appear in force for several years. Then, too, the tillage to kill the weeds sets free fertility. The difficulty in killing this class of plants is the aversion to using the hoe or spade on stray weeds, and since the cultivator always leaves a few to flourish, the land is seldom really cleaned by the hoed or inter-tilled crops. Nevertheless, frequent tillage is of great benefit, because it improves soil texture and conserves moisture.

If the inter-tilled crop is followed by spring-sown cereals, opportunity is given for plowing the ground in the fall and again in early spring. These frequent plowings and the necessary surface tillage may be made a partial substitute for a bare summer fallow in killing weeds and liberating fertility,

and that, too, without losing the use of the land for one season. If the work is not timely nor well done, then the land would better have been treated to a bare summer fallow, especially when it is in a bad physical condition, because frequent plowings in midsummer are usually more beneficial than late fall and early spring plowings are.

Certain classes of weeds infest certain kinds of crops much more than others; when this is the case, rotation may be made to do much to destroy them, by leaving the particular crop out of the rotation in which the weed or weeds appear. This is not difficult, since the ordinary crops of the farm are nearly equal in profit, if labor, use of land, seed, and the amount of fertility carried to town where the products are sold, are all considered. The farmer should study the undesirable plants quite as much as the desirable ones, that he may change or modify his practices so as to attack his enemies at their weakest points.

Rotation on meadows and pastures without plowing can be made to prevent many undesirable plants from asserting themselves. If the land be seeded with a mixture of grasses and clover, or with grasses or timothy alone, some of the seeds are certain to find an uncongenial soil, and the plants either die or become feeble, and even if they flourish at first, many of them exhaust the available food within their reach in a few years. If, then, young and vigorous plants can be introduced, or those having different powers and habits of root growth, or those

which furnish food for the others, a rotation of plants may be made beneficial. Clover is naturally the host-plant of the grasses, and secures its food from much lower depths than most of the grasses do. If seeds of the grasses and clovers can be made to grow in the declining sod without plowing, not only will the full amount of forage be furnished, but undesirable plants will be prevented from occupying the vacant spaces. By sowing a small amount of seed early in the spring, before the freezing has ceased in the north, and winter rains in the south, many young and vigorous plants of different species from those present, or of the same, may be introduced. In order to make the germination and growth more certain, immediately after the seeds are sown the land may be harrowed once or more, and rolled.

Rotation may be made to economize plant-food. Since plants vary in their power to reach and appropriate nourishment, the rotation may be so arranged as to grow those kinds which have the least power, or those which make but little demand on the soil when the land is least fertile. The fertility of the soil in a wise rotation is used, and not carried along as useless capital. Successful agriculture consists quite as much in taking fertility out of the soil judiciously as in putting it into the soil. Therefore, in planning a rotation where circumstances allow freedom of choice, the object should be to change inorganic elements into organic substances; that is, to get the largest possible crops consistent with the largest net

results, not alone on account of the immediate results, but also in order to have more manures to return to the fields. Or, to express it in another way, the greater the quantity of plant-food that can be made to rotate through the plants and animals back to the land, the better. Transforming the elements of the soil into plant-life does not destroy them,—it only changes their combinations, and the oftener they are rotated the better they are likely to become, for as soon as left idle they tend to become sluggish.

If the inert matters of the vegetable mold and the rocks be made to change their combinations by tillage so as to become available for the plant, they are not only on their way to become useful, but also the quality of the elements tends to be improved, for plants break down easily, and when broken down furnish quickly available nourishment to other plants; or, if they be fed to animals, the resultant excrement will yield up its nourishment for other plants still more readily. Nature provides plants to feed animals, animals to produce fertility, fertility to feed other plants; this rotation preserves the elements of productive power, while they are constantly changing their form and character.

To illustrate how a less exacting crop may be made to follow advantageously a more exacting one, the four-year rotation now frequently adopted since the clover root-borer has made its appearance may be cited. One year of clover is followed by maize with or without manure, this by the less exacting oats, then wheat, phosphated and manured, and lastly, the

partly self-sustaining clovers, or clover and grasses. This rotation not only tends to clean the land, but also maintains fertility, and makes it possible to reach satisfactory results with but one, or at most, two manurings in four years, the less exacting crops being able to flourish on the residue of plant-food left from the liberally fertilized wheat and decayed clover roots. Some clover should always accompany the hay and pasture grasses, if a well-balanced plant ration is to be maintained in the soil.

Rotation not only gives opportunity to make economical use of the land, but it may also be made to head off many kinds of insect enemies and plant diseases. If plants of a single variety or species are grown continuously on the same land, its insect enemies are likely to multiply rapidly, since they are furnished with a full and continuous supply of the particular kind of food upon which they thrive best, while if a wise rotation is practiced they may be starved out in many cases. Fields kept long in grass are likely to become infested with wire-worms and the white grub (larva of the May beetle). If a short rotation is practiced, few of them are likely to be present. In any case, when land and conditions will permit, a short rotation is preferable to a long one. In like manner many of the smuts, rusts and blights may be entirely prevented or largely controlled by superior tillage and by adopting such a rotation as will give them but little opportunity to find a host upon which to live. Some of the pests of the farm can migrate to a considerable distance in a

single season when in their mature state. In that case, it may be of little use to prevent the multiplication of them on one's own farm, if the unwise practices of a neighbor have made his land a breeding-place for pests, such as wire-worms and white grubs. If by consultation and coöperation of neighbors a common line of action could be secured, some of the difficulties of farming might be ameliorated.

Rotation may be made to distribute the work of the year, thereby providing continuous employment, and making it possible to secure cheaper and better help than when only a few kinds of plants are produced. The baleful results of raising a single or few products in extended districts may be seen in California and the great wheat districts of the northwest. In such localities there is little or no true home life, with its duties and restraints; men and boys are herded together like cattle, sleep where they may, and subsist as best they can. The work is hard, and from sun to sun for two or three months, when it abruptly ceases, and the workmen are left to find employment as best they may, or adopt the life and habits of the professional tramp. It is difficult to name anything more demoralizing to men, and especially to boys, than this intermittent labor; and the higher the wages paid and the shorter the period of service, the more demoralizing the effect. If there were no other reason for practicing rotation with a variety of plants, the welfare of the workman and his family should form a

sufficient one. Happily many large and demoralizing wheat ranches are being divided into small farms, upon which are being reared the roof-tree, children, and flowers.

Both two and four-year rotations have been mentioned. There is still another, which should come into common use on fairly fertile, lightish lands, if circumstances will permit. It consists of one year of clover, one of potatoes, and one of wheat. The three crops may be secured with but one plowing. The clover stubble may be plowed either fall or spring, after two cuttings of hay, or one of hay and one of clover seed; or, in lieu of the seed, fall pasture. The following spring, if potatoes are planted early, they may be harvested in time to prepare a seed-bed with the cultivator and harrow for wheat. As potatoes are deep-feeding plants, they draw but little nourishment from the upper portion of the soil, while the tillage necessary to keep down weeds and to conserve moisture sets free an abundance of plant-food near the surface, and compacts the sub-surface soil, thus securing ideal conditions for winter wheat. A light dressing of potash and phosphoric acid might be applied to supplement the farm manures. If the land is sandy, a small addition of nitrogen may be advantageously made both fall and spring. The rotation may be changed from a three to a four-year one by seeding with a mixture of grasses and clover, which will continue to furnish hay for two consecutive years. Although the three-year rotation is but little practiced, it may be confi-

dently recommended where potatoes, wheat and clover all do well. This rotation may be made to keep the land fairly fertile and free from noxious weeds. Clover, hay, straw and small potatoes form together a cheap and almost ideal ration for wintering sheep, horses and cattle, and such a ration needs but little addition of appropriate concentrated foods to make it ideal for milch cows. In this three-year rotation, the surface and subsoil both furnish their due proportion of nourishment, the crops are among the most valuable produced, the work is well distributed through the year, and the principal income is distributed between the wheat, the butter and meats, and the potatoes, so that an entire failure is not likely to occur. Moreover, but few pests are likely to get a foothold, the plant-food taken up by the crops is largely left on the farm to be used again (see "Clover," in Chapter XIV.), and the crops are raised with the minimum of plowing. While this rotation is adapted only to certain conditions, longer and shorter ones under similar circumstances may be made to unlock fertility and to yield satisfactory results if intelligently planned and persistently pursued.

Where the land is hilly, or difficult and expensive to cultivate, a long rotation is desirable, that the great amount of labor necessary to cultivate such lands successfully may be avoided. This is especially true of soil that is composed largely of tenacious clay. Then, too, such land being usually abundantly supplied with plant-food, and the natural home of most grasses, the rotation may well be one in which mixed

grasses and clovers are prominent. Long rotations are adapted to large estates, while short ones may be adopted on small, well-drained, high-priced farms.

A few rotations have now been given to illustrate the chief benefits that may be expected from an intelligent choice of plants, when one has in view both the welfare of the soil and economy of effort. It is fully realized that a multitude of combinations may be made that are better suited to local and individual wants than those cited. It is also realized that success may be secured in exceptional cases by the constant cultivation of a single species or variety of plants. The writer has raised maize for seven consecutive years successfully in a little, sheltered, gravelly valley, partly as an experiment and partly because it could be kept productive by the application of cheap manures, easily accessible, and because this field could be planted and harvested earlier than the other fields, thereby distributing the work of raising maize and filling the silo advantageously. This case is cited, not only to show that a wise law may be broken under exceptional cases, but also to emphasize the need of an understanding of the beneficial laws of rotation when applied under prevailing conditions, in order that the losses and gains by any particular practice may be fully understood and set over one against the other. Rotations, if planned to suit locality, and carried on with a fair understanding of natural conditions, may be made to increase the fertility of the farm; that is, give it greater productive power.

APPENDIX A.

FERTILIZING CONSTITUENTS OF VARIOUS PRODUCTS.

These figures are compiled from the following sources: (1) Yearbook of the United States Department of Agriculture, 1894. Washington, D. C., Government Printing Office, 1895. (2) Fütterungslehre, A. Conradi. Paul Parey, Berlin, 1895. (3) How Crops Grow, Samuel W. Johnson. Orange Judd Co., New York, 1891. (4) Landwirtschaftlicher Kalender for 1896. Paul Parey, Berlin, 1896. (5) Landwirtschaftliche Fütterungslehre, E. von Wolff. Paul Parey, Berlin, 1895. (6) Zusammensetzung und Verdaulichkeit der Futtermittel, Th. Dietrich and J. König. Julius Springer, Berlin, 1891. (7) Cornell University Experiment Station Analyses. (8) Analyses collected from various and incidental sources by the Cornell University Experiment Station.

Index to the divisions in the following tables:

NOTE.—By moving decimal points one place to the left, the reader may make the figures express percentages.

I. Animal Excrements—

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
		Lbs. in 1,000.				
Fresh from duck	4	566.	72.	10.	14.	6.2
" " geese	4	771.	95.	5.5	5.4	9.5
" " chickens	4	560.	85.	16.3	15.4	8.5
" " "	1	600.		11.	8.5	5.6
" " pigeon	4	519.	173.	17.6	17.8	10.

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Fresh from horse	4	713.	33.	5.8	2.8	5.3
" " "	7	931.		4.4	1.7	3.5
" " ox	4	775.	22.	3.4	1.6	4.
" " sheep	4	646.	36.	8.3	2.3	6.7
" " swine	4	724.	26.	4.5	1.9	6.
Human excrements, fresh	4	772.	30.	10.	10.9	2.5
" " "	1	959.		6.	1.7	2.
" urine, fresh	4	963.	13.	6.	1.7	2.
Mixture of both, fresh	4	935.	14.	7.	2.6	2.1
Liquid manure	4	982.	11.	1.5	.1	4.9
Ordinary manure, fresh	4	750.	38.	3.9	1.8	4.5
Ordinary manure, somewhat rotted	4	750.	58.	5.	2.6	6.3
Ordinary manure, well rotted	4	790.	65.	5.8	3.	5.
Pigeon manure, dry	1	100.		32.	19.	10.
Sewage fluid	4	955.	15.	5.5	2.8	2.
" " in large cities	4	974.	11.	4.5	1.9	2.
Urine, fresh, horse	8	901.	28.	15.5		15.
" " cattle	8	938.	27.4	5.8		4.9
" " sheep	8	872.	45.2	19.5	.1	22.6
" " swine	8	967.	15.	4.3	8.3	.7
II. Animal Products—		Lbs. in 1,000.				
Blood, calf	8	800.	7.1	29.	.6	.8
" ox	4	790.	7.9	32.	.4	.6
" sheep	8	790.	7.5	32.	.4	.5
" swine	8	800.	7.1	29.	.9	1.5
" meal (3)	6	84.5	47.3	135.	13.5	7.7
Butter	1	79.1	1.5	1.2	.4	.4
Buttermilk	1	905.	7.	4.8	1.7	1.6
" (85)	6	901.2	7.2	6.4	2.2	2.1
Cheese	1	332.5	21.	39.3	6.	1.2
Colostrum	4	730.	11.8	30.7	3.3	.9
Cream	1	740.5	5.	4.	1.5	1.3
Eggs	8	672.	61.8	21.8	3.7	1.5
" without shell	4	737.	9.2	20.	3.5	1.6
Fat renderings, cakes (5)	6	95.2	63.8	93.8	26.2	19.9
Fish-flesh, meal, not fatty (4)	6	128.	326.	83.9	140.	3.
" " " fatty (6)	6	108.	292.1	77.5	120.	2.

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Flesh albumin (2)	6	123.6	119.7	99.4	21.	3.
" fodder meal (144)	6	106.7	40.8	113.9	7.	1.
" meal	8	278.	156.	97.	63.	7.
" calf	8	780.	12.	34.9	5.8	4.1
" ox	8	770.	12.6	36.	4.3	5.2
" swine	8	740.	10.4	34.7	4.6	3.9
" of mammals	4	763.	10.2	35.2	4.2	3.8
" " living calf	4	662.	38.	25.	13.8	2.4
" " living ox	4	597.	46.6	26.6	18.6	1.7
" " living sheep	4	591.	31.7	22.4	12.3	1.5
" " living swine	4	520.	21.6	20.	8.8	1.8
" " pulverized dead animals	8	57.	374.	65.	139.	3.
Milk, cow's	1	870.	7.5	5.3	1.9	1.8
" "	4	875.	7.2	5.4	2.	1.7
" " (793)	6	871.7	7.1	5.7	1.9	1.7
" goat's (38)	6	857.1	7.6	6.8	3.7	2.1
" mare's (47)	6	908.	3.5	3.2	2.1	.8
" sheep's	4	816.	7.3	11.2	2.6	1.6
" " (33)	6	808.	8.9	10.4	5.	2.9
" "	8	860.	8.4	5.5	3.	1.8
" skim	1	902.5	8.	5.6	2.	1.9
" "	4	911.	7.9	4.6	2.2	2.1
" " (96)	6	904.3	7.	5.2	2.1	2.
" " centrifugal separation (7)	6	906.	7.4	4.9	2.1	2.
Milk, sow's (7)	6	845.5	11.	10.3	6.	1.1
Whey	1	929.7	6.	1.5	1.4	1.8
"	4	932.	5.4	.9	.9	1.7
" (46)	6	933.8	6.5	1.4	1.1	2.
" from goat milk	4	920.	5.9	1.5	.8	2.3
Wool, washed	4	128.	9.8	94.4	1.8	1.9
" unwashed	4	150.	70.8	54.	.7	56.2

III. Bedding Materials—

		Lbs. in 1,000				
Beech leaves, August	4	560.	21.6	13.	1.8	4.4
Fir needles	4	135.	12.2	8.	1.	1.3
Heath	8	200.	16.6	10.	1.1	2.1
Larch needles	4	140.	34.3		1.3	1.6
Moss	4	250.	20.6	10.5	1.6	3.4
Oak leaves	4	160.	46.1	10.	2.	3.5

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Pine needles	4	126.	40.3	9.	2.	1.3
Reed	4	180.	33.5		1.8	6.
Rush	4	140.	56.		4.3	16.9
Seaweed	4	150.	146.7	16.4	4.2	17.7
Sedge grass	8	140.	16.2		4.6	17.7
IV. Chaff, Hulls and Shells—		Lbs. in 1,000.				
Barley	1	130.8		10.1	2.7	9.9
"	4	143.	118.6	4.8	2.4	9.3
" (3)	6	145.	128.4	4.7	2.4	9.4
Beans, field	4	150.	54.7	16.8	2.7	35.5
" "	2	150.	74.	17.		
" " (2)	6	150.	74.3	17.7	2.7	35.3
" "	5	150.	55.	16.8		
Bean, soja	2	110.	81.	9.6		
" " (6)	6	120.	81.	10.1	1.7	9.7
Brassica rapa oleifera (2)	6	152.	78.	5.5	3.6	9.3
Chocolate tree (*Theobroma Cacao*) (14)	6	100.	77.7	22.7	4.5	15.3
Clover, red (4)	6	160.	84.8	22.3	4.2	16.8
" white (1)	6	150.	75.8	36.6	4.2	17.
Corn cobs (18)	1	107.	14.	3.84		
" "	1	120.9	8.2	5.	.6	6.
" "	4	140.	4.5	2.3	.2	2.3
" "	5	131.	23.	5.6		
" " ground (4)	6	100.	31.8	13.1	.9	2.7
Cotton (4)	1	104.	26.	6.4		
"	1	106.3	26.1	7.5	1.8	10.8
" (1)	6	133.	27.	6.2	4.3	10.4
Flax (*Camelina sativa*)	4	112.	43.3	4.3	1.5	12.7
" " " (1)	6	111.6	72.3	4.3	1.5	12.7
" " "	5	112.	72.	4.3		
" (*Linum usitatissimum*)	4	116.	53.9	5.6	4.5	15.
" " " (1)	6	115.8	57.8	5.5	4.4	15.
" " "	5	116.	58.	5.6		
Gleditschia glabra (1)	6	82.4	29.5	7.2	1.8	10.1
Lentil (*Lens esculenta*) (2)	6	150.	70.1	29.3	8.5	8.5
Lentil (*Lens esculenta*)	5	140.	85.	33.9		
Lupine (fruit shell)	4	143.	19.1	7.2	1.	9.4

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Lupine (fruit shell)	2	125.	29.	7.2		
" " " (7)	6	150.	59.2	10.8	1.7	9.3
Medick, Black (*Medicago lupulina*) (1) chaff	6	150.	80.4	45.	4.2	17.
Millet (1) "	6	120.	111.8	7.5	1.7	4.4
" "	5	112.	112.	7.7		
Oats "	4	143.	71.2	6.4	1.3	4.5
" "	2	136.	110.	7.8		
" (52) "	6	138.	104.7	8.	1.4	4.5
Peanut (fruit shell)	1	100.	29.9	10.4	1.4	8.1
" " "	4	106.	30.	11.4	1.7	9.5
" " " (2)	6	106.	30.	11.3	1.8	9.8
" " "	5	106.	30.	11.4		
" (seed shell) (1)	6	108.	51.	35.8	8.9	8.9
Peas (4) hulls	6	130.	58.8	17.4	1.7	9.5
" "	2	140.	72.	16.5		
Rape (*Brassica Napus oleifera*) "	4	140.	70.1	6.4	3.7	9.5
" " " " "	2	122.	65.	6.4		
" " " " (12) "	6	160.	70.6	5.5	3.6	9.2
" " " " "	5	129.	76.	6.7		
Rice (3) "	1	82.	132.	5.8		
" "	4	100.	90.	5.	1.7	1.4
" (10) "	6	100.	145.	5.8	1.7	1.4
" "	5	97.	157.	5.4		
Rye chaff	3	143.	82.7	5.8	5.6	5.2
" "	2	143.	75.	5.7		
" (4) "	6	145.	82.6	7.	5.5	5.1
" winter "	4	143.	82.7	5.8	5.6	5.2
Sorghum (*S. Tataricum*) (1) "	6	145.	72.3	5.6	1.7	4.3
" (*S. vulgare*) "	5	57.	80.	6.2		
Spelt, winter "	4	143.	81.4	5.6	5.9	7.7
" (1) "	6	145.	83.5	4.6	6.	7.7
Vetch or tare (4) "	6	143.	87.8	14.9	2.7	35.1
" " "	5	150.	80.	13.6		
Wheat "	1	80.5	71.8	7.9	7.	4.2
" "	3	143.	92.	7.2	4.	8.4
" "	2	143.	119.	6.8		
" (31) "	6	160.	101.	7.4	3.8	8.2
" winter "	4	143.	92.	7.2	4.	8.4

V. Commercial Plants—

Sample (No. of analyses in parentheses).	Authority.	Lbs. in 1,000. Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Flax, fiber	4	100.	6.8		.7	.3
" stems	4	120.	31.1		4.2	9.7
" " roasted	4	100.	7.		.8	.3
Grape stalks	4	630.	21.2	5.6	1.8	10.9
" must	4	840.	4.7	1.8	.6	3.1
" wood and twigs	4	550.	12.7	4.1	1.4	4.1
Hemp, stems	4	108.	31.7		2.1	5.5
Hops, whole plant	4	140.	72.9	25.	5.8	17.9
" stems	4	160.	38.3	15.7	3.9	11.2
" flowers	4	120.	66.3	32.2	11.1	23.
Mulberry leaves	4	720.	30.1	14.	2.4	7.3
Tobacco leaves	4	180.	140.7	24.5	6.6	40.9
Tea leaves	4	80.	47.6	35.6	7.2	16.4
Wine grounds	4	650.	36.7		4.6	17.2

VI. Fertilizing Materials—

Sample	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Ammonite	1	58.8		113.	34.3	
Ammonium sulfate	4	40.		205.		
Ash of deciduous trees	4	50.	90.		35.	100.
" " evergreen "	4	50.	90.		25.	60.
Ashes, leached wood	1	302.			15.1	12.7
Bat guano	1	400.		82.	38.	13.1
Blood meal	4	134.	82.	118.	12.	7.
Bone, ash	4	60.	910.		354.	3.
" black	1	46.			28.28	
" "	8	60.	840.	10.	32.	1.
" " used	8	100.	840.	5.	26	1.
" " dissolved	1				17.	
" charcoal	4	150.	780.	5.	160	
" meal	4	130.	232.	23.	176.	1.
Calcium phosphate	4	277.	597.	15.	195.	1.
Carnallit	4	261.				98.
Castor pomace	1	95.		55.	17.5	11.
Clover, red, root nodules	7	793.7		11.		
Corn smut	8	83.		20.9		
Cotton-hull ashes	1	78.			88.5	227.5
Fish guano, Norway	4	98.	340.	85.	138.	3.
Gas lime	4	70.	917.	4.		2.
Horn meal and shavings	4	85.	230.	102.	55	

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Kainit	4	127.				128.
Kieserit	4	207.				75.
Marl	8	56.9			5.5	7.9
" (N. J.)	1	15.			30.	52.
Molasses ash from sugar beet	4	65.	843.		10.	321.
Muck	1	500.		11.	1.	1.5
Nitrate of potash	1	19.3		130.9		451.9
" " soda	1	14.		157.		
Oleomargarine refuse	1	85.4		121.	8.8	
Oyster-shell lime	1	150.			1.8	.5
Potassium and magnesium sulfate	4	116.				272.
Potassium chloride, 80%	4	11.				527
Potassium sulfate, 90%	3	22.				499.
Pea, cow, roots	8	101.6	199.7	6.8	6.4	14.6
Peat	1	615.		8.5	.8	1.8
" ashes	8	50.	925.		6.	15.
Phosphate, Florida	4				320.	
" Canada	4				390.	
" South Carolina	4	5.	965.		265.	
Phosphate, South Carolina dissolved rock	8	120.	880.		152.	
Peruvian guano	4	150.	430.	70.	140.	33.
Seaweed	8	439.4		19.3	4.3	26.6
" ashes	1	14.7			3.	9.2
Sewage	4	974.	11.	4.5	1.9	2.
Soot, wood	4	50.	282.	13.	4.	24.
" coal	4	50.	331.	24.	4.	1.
Spent tan-bark ashes	1	36.			16.1	20.4
Star fish	8	687.8	160.9	17.2	2.5	4.8
Soot from wood	8	50.	272.	13.	4.	23.
" " hard coal	4	50.	281.	24.	4.	1.
Sodium nitrate	4	26.		155.		
Sugar house scum	8	345.	410.	12.	15.	2.
Sumac waste	1	630.6		11.9		32.5
Sylvinit	4	65.				124.
Tankage	1	100.		67.	118.	
Tannery refuse	4	633.	188.	14.	13.	
Thomas slag	4				175.	
Tobacco stalks	1	61.8		37.1	6.5	50.2

Sample (No. of analyses in parentheses.)	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Tobacco stems	4	180.	64.7	16.4	9.2	28.2
Wool dust, etc	4	100.	340.	52.	13.	3.
VII. Fruits, Leaves and Nuts		Lbs. in 1,000.				
Apple leaves, collected in May	1	723.6	23.3	7.4	2.5	2.5
" " " " Sept	1	607.1	34.6	8.9	1.9	3.9
" fruit	1	853.	3.9	1.3	.1	1.9
" "	4	831.	2.2	.6	.3	.8
" trees (young), branches	1	836.	6.5		.4	.4
" " " roots	1	647.	15.9		1.1	.9
" " " trunks	1	517.	11.7		.6	.6
" " " whole plant	1	608.3		3.5	.5	1.7
Apricots, fresh	1	851.6	4.9	1.9	.6	2.9
Banana	1	662.5	11.5	.8		
Blackberries	1	889.1	5.8	1.5	.9	2.
Blueberries	1	826.9	1.6	1.4	.5	.5
Cherries, fruit	1	861.	5.8	1.8	.6	2.
" "	4	825.	3.9		.6	2.
Cherry trees (young), branches	1	795.	7.8		.5	.6
" " " roots	1	672.	12.2		.8	.7
" " " trunks	1	532.	8.1		.4	.6
Chestnuts, native	1	400.	16.2	11.8	3.9	6.3
" cultivated	1	400.	17.8			
" Spanish	1	100.	26.6			
China berries	1	165.2	41.3	11.9	4.3	23.3
Cranberries, fruit	1	895.9	1.8		.3	.9
" vines	1		24.5		2.7	3.2
Currants	1	860.2	5.3		1.1	2.7
Grapes, fruit (fresh)	1	830.	5.	1.6	.9	2.7
" " "	4	830.	8.8	1.7	1.4	5.
" wood of vine	1		29.7		4.2	6.7
Gooseberries	4	903.	3.3		.7	1.3
Lemons	1	838.3	5.6	1.5	.6	2.7
Nectarines	1	790.	5.	1.2		
Olives, fruit	1	580.	14.2	1.8	1.2	8.6
" leaves	1	424.	25.1	9.1	2.6	7.6
" wood of larger branches	1	145.	9.4	8.8	1.1	1.8
" " " small "	1	187.5	9.6	8.9	1.2	2.
Oranges, California	1	852.1	4.3	1.9	.5	2.1
" Florida	1	877.1		1.2	.8	4.8

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid	Potash.
Palm nut	5	76.	18.	13.4		
Peaches, fruit	1	878.5	3.2		.5	2.4
" wood of branches	1	582.6	19.3	9.	2.2	5.
Peanuts, hulls	1	100.	29.9	10.4	1.4	8.1
" kernels	1	100.	22.1	40.1	8.2	8.8
" vines, after blooming	1	100.	123.6		2.9	9.
" " before "	1	300.	74.5		3.2	11.6
Pears, fruit	1	839.2	5.4	.9	.3	.8
" "	4	831.	3.3	.6	.5	1.8
" trees (young), branches	1	840.	7.6		.4	.8
" " " roots	1	667.	14.		.7	1.1
" " " trunks	1	493.	17.1		.7	1.3
Pineapples	1	892.8	3.5	.2		
Plums	1	474.3	5.4	1.8	.2	2.4
"	4	838.	2.9		.4	1.7
Prunes	1	773.8	4.9	1.6	.7	3.1
Raspberries	1	818.2	5.5	1.5	4.8	3.5
Strawberries, fruit	1	908.4	6.	1.5	1.1	3.
" "	4	902.	3.3		.5	.7
" vines	1		33.4		4.8	3.5
Whortleberries	8	824.2	4.1			

VIII. Green Fodders

		Lbs. in 1,000				
Alfalfa	1	753.	22.5	7.2	1.3	5.6
"	4	740.	19.2	7.2	1.6	4.5
" (11)	6	760.	22.1	6.2	1.5	3.5
Apple pomace, silage	6	750.	10.5	3.2	1.5	4.
Aspen, American (4)	6	700.	28.	6.4	1.8	7.2
Barley, during and at end of bloom (11)	6	686.3	20.1	3.3	2.	5.1
Bean, horse (*Vicia Faba*)	1	747.1		6.8	3.3	13.7
Bean, horse (*Vicia Faba*), beginning of bloom (3)	6	850.	19.8	5.1	1.3	8.
Beech, European, August and September (4)	6	570.	31.2	11.	1.7	4.7
Birch, European white, in August (3)	6	550.	15.7	12.7	1.3	3.4
Buckwheat, in bloom	4	850.	12.4	3.9	.8	3.8
" " " (7)	6	837.	11.4	4.	.7	2.8
Clover, Alsike	1	818.	14.7	4.4	1.1	2.

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Clover, Alsike	4	820.	8.6	5.3	.9	2.4
" " (3)	6	818.	14.7	4.4	1.1	2.
Clover, Bokhara, beginning and full bloom (6)	6	797.	23.4	6.6	2.4	6.7
Clover, crimson	1	825.		4.3	1.3	4.9
" "	4	815.	11.3	4.3	.8	2.6
" " (9)	6	815.	18.6	4.5	1.2	4.
" red, very young	4	860.	14.	6.	1.7	5.1
" " " " (18)	6	832.	18.	6.9	2.1	6.1
" " in bud	4	820.	14.7	5.3	1.5	5.5
" " " " (11)	6	841.	14.	5.3	1.3	4.8
" " " bloom	4	800.	13.7	4.8	1.3	4.4
" " " " (42)	6	790.	16.	5.4	1.5	4.8
" " " "	1	800.		5.3	1.3	4.6
" white	1	810.		5.6	2.	2.4
" " in bloom	4	805.	14.3	5.6	1.8	3.1
" " " " (3)	6	815.	21.1	7.1	2.1	3.6
" pasture	4	750.	16.4	5.3	1.6	7.6
" " (21)	6	850.	13.5	5.8	1.8	6.5
" yellow	8	830.	14.7	4.5	1.1	3.2
Erica vulgaris, before blooming (3)	6	500.	29.	5.6	.5	2.5
Esparsette, in bloom	4	800.	11.	5.1	1.1	3.1
" " " (3)	6	800.	12.2	5.6	1.1	3.2
Grape, July	6	746.	19.8	9.6	2.6	4.6
" August	6	760.	18.3	7.	1.9	4.3
" harvest	6	540.	49.2	6.5	1.3	4.6
Hop, leaves and stems	6	660.	41.	7.5	4.	8.8
Italian rye-grass (*Lolium Italicum*), in bloom (8)	6	748.5	28.4	5.4	2.9	11.4
Lupine, yellow (*Lupinus luteus*), beginning of bloom (7)	6	878.	10.	4.7	1.2	1.4
Maize, fodder	1	786.1	48.4	4.1	1.5	3.3
" "	4	829.	10.4	1.9	1.	3.7
" " (45)	6	828.	14.7	2.2	1.1	3.9
" "	8	822.	12.	1.9	1.3	4.3
" European seed (34)	6	806.	12.2	2.7	1.	3.9
" husks	8	861.9	5.6	1.8	.7	2.2
" stalks	8	808.6	12.5	2.8	1.4	4.1
" silage	1	779.5		2.8	1.1	3.7

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid	Potash.
Maple foliage, in summer (5)	6	500.	72.9	13.	3.5	8.
Medick, black (*Medicago lupulina*), beginning of bloom (4)	6	800.	16.4	5.5	1.	4.
Millet	1	625.8		6.1	1.9	4.1
" (6)	6	870.	12.	2.2	.7	4.7
" Japanese..................	1	710.5		5.3	2.	3.4
Mixed grasses....................	1	631.2	32.7	9.1	2.3	7.5
" "	4	700.	22.1	5.4	1.8	7.1
" " in bloom..........	4	750.	17.5	4.8	1.2	4.7
" " " " (31)......	6	700.	21.	4.9	1.7	6.2
Mohar (*Setaria Germanica*), beginning of bloom	4	750.	17.4	5.	1.	6.3
Mohar (*Setaria Germanica*), during bloom (6)................	6	730.	23.	4.5	1.	6.1
Mulberry (34)....................	6	692.7	35.1	9.5	2.4	8.4
Mustard, white, beginning to full bloom (6)....................	6	851.	14.2	4.5	1.6	2.6
Needles from pines and firs in fall (3)......................	6	508.	19.7	7.1	1.7	2.9
Nettle (*Urtica dioica*), young (2)	6	832.	22.7	8.7	2.3	3.4
Oats, in bloom (12)..............	6	768.5	17.6	3.1	1.8	6.8
" ripening (11)..............	6	536.	28.	5.5	2.6	8.8
" green......................	8	810.	18.8	3.7	1.7	7.5
" "	4	810.	14.2	3.7	1.3	5.6
Oat-fodder......................	1	833.6	13.1	4.9	1.3	3.8
Orchard grass (*Dactylis glomerata*)	4	700.		17.8	1.3	5.9
Orchard grass (*Dactylis glomerata*), before and at beginning of bloom (5)..................	6	796.	18.6	3.3	1.3	6.5
Orchard grass (*Dactylis glomerata*), in bloom (12)..........	6	631.4	20.9	4.3	1.6	7.6
Orchard grass (*Dactylis glomerata*), luxuriant growth (2)..	6	861.	16.	5.1	1.3	6.5
Pea..............................	4	815.	13.9	5.1	1.5	5.2
" (3)...........................	6	824.	13.3	5.7	1.6	5.
Pea, flat (*Lathyrus sylvestris*), beginning to end of bloom (6)	6	716.	19.3	11.3	1.8	5.8
Prickly comfrey (*Symphytum asperrimum*) (17)...........	6	885.	19.8	3.9	.7	4.8

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Prickly comfrey (*Symphytum asperrimum*)	1	843.6	24.5	4.2	1.1	7.5
Rape (*Brassica Napus oleifera*), beginning of bloom	4	870.	10.5	4.6	1.2	3.5
Rape (*Brassica Napus oleifera*), in bloom (6)	6	855.	13.4	4.5	1.5	3.6
Rye	1	621.		3.3	1.5	7.3
"	4	760.	16.3	5.3	2.4	6.3
" (9)	6	766.	17.4	5.3	2.5	7.1
"	8	669.	21.5	4.8	2.6	7.6
" grass	4	700.	20.4	5.7	2.2	7.1
Rye grass, English (*Lolium perenne*), in bloom (13)	6	752.	26.	4.7	2.8	11.
Rye grass, French (*Avena elatior*) (9)	6	684.8	29.	5.6	2.2	9.3
Serradella, in bloom	1	825.9	18.2	4.1	1.4	4.2
" " "	4	800.	19.6	4.8	2.2	7.7
" " " (6)	6	823.	14.5	5.	1.6	5.5
Sorghum (*S. saccharinum*), in bloom	8	773.	13.	4.	.8	3.6
Sorghum (*S. saccharinum*), in bloom	1	821.9		2.3	.9	2.3
Sorghum (*S. saccharinum*), in bloom (26)	6	801.5	13.7	3.3	.7	3.4
Sorghum (*S. saccharinum*), in bloom	4	773.	14.	4.	.8	3.9
Spurry (*Spergula arvensis*), in bloom (9)	6	803.	21.	3.8	2.5	5.9
Timothy, beginning to end of bloom	4	700.	20.5	5.4	2.4	7.1
Timothy, beginning to end of bloom (22)	6	669.	21.5	4.8	2.6	7.6
Vetch, in bloom (6)	6	825.	15.4	5.1	1.2	4.3
" beginning of bloom (3)	6	845.	19.4	5.9	1.9	7.
Vetch, Russian or hairy (*Vicia villosa*), beginning to end of bloom (7)	6	834.	13.9	6.6	1.6	4.1
Vetch, kidney (*Anthyllis vulneraria*), before and beginning of bloom (4)	6	820.	13.5	3.8	1.1	3.3

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Vetch, kidney (*Anthyllis vulneraria*), in bloom	4	830.	10.9	4.5	1.	3.
Wheat (4)	6	767.	21.9	5.4	1.5	7.
IX. Hay—			Lbs. in 1,000			
Alfalfa (*Medicago sativa*) (21)	1	84.	74.	22.9		
" " "	1	65.5	70.7	21.9	5.1	16.8
Alfalfa (*Medicago sativa*), beginning of bloom	1	160.	62.	23.	5.3	14.6
Alfalfa (*Medicago sativa*), beginning of bloom	2	167.	60.	23.		
Alfalfa (*Medicago sativa*) beginning of bloom (15)	6	157.5	73.1	23.9	5.4	14.9
Alfalfa (*Medicago sativa*) in bloom (117)	6	153.	80.2	22.9	6.1	17.9
Alfalfa (*Medicago sativa*) in bloom	5	160.	62.	23.		
Alfalfa, Black Medick (*Medicago lupulina*) (7)	6	160.	75.2	24.6	5.4	20.8
Alpine hay	4	150.	29.7	18.5	2.7	7.7
" " (43)	6	145.	64.3	19.3	6.8	18.6
" "	5	143.	62.	21.6		
Bean (field), in bloom (1)	6	160.	67.5	29.6	6.4	20.5
" soja, whole plant	1	63.	64.7	23.2	6.7	10.8
Black grass (*Juncus Gerardi*) (20)	1	95.	70.	12.		
Blue melilot (*Melilotus cœruleus*)	1	82.2	136.5	19.2	5.4	28.
Buckwheat (3)	1	99.	55.	8.3		
"	4	160.	51.7	13.	6.1	24.2
"	2	121.	52.	6.6		
" (12)	6	160.	70.2	7.7	6.1	24.2
"	5	104.	50.	6.2		
" Japanese	1	57.2		16.3	8.5	33.2
Couch grass (*Agropyrum repens*) (5)	1	143.	60.	14.1		
Clover, Alsike (*Trifolium hybridum*) (9)	1	97.	83.	20.5		
Clover, Alsike (*Trifolium hybridum*)	1	99.4	111.1	23.4	6.7	22.3
Clover, Alsike (*Trifolium hybridum*)	4	160.	40.	24.	4.1	11.1

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Clover, Alsike (*Trifolium hybridum*)	2	169.	61.	23.7		
Clover, Alsike (*Trifolium hybridum*), in bloom (10)	6	160.	71.2	21.6	5.	13.9
Clover, Alsike (*Trifolium hybridum*), in bloom	5	160.	60.	24.		
Clover, Bokhara (*Melilotus alba*)	1	74.3	77.	19.8	5.6	18.3
" " " "	2	136.	83.	25.3		
Clover, Bokhara (*Melilotus alba*), young	5	143.	80.	26.7		
Clover, crimson (*Trifolium incarnatum*)	4	167.	50.7	19.5	3.6	11.7
Clover, crimson (*Trifolium incarnatum*)	2	139.	69.	17.1		
Clover, crimson (*Trifolium incarnatum*) (9)	6	183.	77.	20.5	4.	13.1
Clover, crimson (*Trifolium incarnatum*)	5	167.	51.	19.5		
Clover, mammoth red	1	114.	87.2	22.3	5.5	12.2
Clover, red (*Trifolium pratense*) (38)	1	153.	62.	19.7		
Clover, red (*Trifolium pratense*)	1	113.3	69.3	20.7	3.8	22.
" " " "	2	160.	56.	21.4		
Clover, red (*Trifolium pratense*) (59)	6	163.	62.8	21.8	5.6	18.9
Clover, red (*Trifolium pratense*)	5	160.	53.	19.6		
Clover, red, young	4	167.	82.3	35.5	10.	29.7
" " in bud	4	165.	68.4	24.5	6.9	25.3
" " " " (20)	6	162.	80.1	22.9	6.9	25.4
" " in bloom (6)	1	208.	66.	18.4		
" " " "	4	160.	57.6	19.7	5.6	18.6
" " " " (178)	6	170.	62.1	21.2	5.5	18.7
" " ripening	4	150.	44.7	12.5	4 4	10.
Clover, red (*Trifolium medium*) (10)	1	212.	61.	17.1		
Clover, red (*Trifolium medium*)	1	114.	87.2	22.3	5.5	12.2
Clover, red (*Trifolium medium*) in bloom (5)	1	209.	66.	78.4		
Clover, white, in bloom (7)	1	97.	83.	25.1		
" " " "	1			27.5	5.2	18.1

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Clover, white, in bloom	4	165.	61.1	23.2	7.8	13.1
" " " "	2	167.	95.	23.8		
" " " " (6)	6	160.	67.	23.8	7.8	13.2
" " " "	5	165.	60.	23.2		
French rye grass (*Avena elatior*), cut in bloom (15)	6	143.	81.2	16.6	6.	24.
French rye grass (*Avena elatior*), cut in bloom	5	143.	99.	17.9		
Hedysarum coronarium	1	93.9		24.6	4.5	20.9
Hungarian grass (*Setaria Italica*) (12)	1	77.	60.	12.		
Hungarian grass (*Setaria Italica*)	1	76.9	61.8	12.	3.5	13.
Italian rye grass (*Lolium Italicum*), cut in bloom	1	87.1		11.9	5.6	12.7
Italian rye grass (*Lolium Italicum*), cut in bloom (6)	6	120.	102.5	20.8	7.6	24.6
Italian rye grass (*Lolium Italicum*), cut in bloom	5	143.	78.	17.9		
Kentucky blue grass (*Poa pratensis*)	1	103.5	41.6	11.9	4.	15.7
Lotus villosus	1	115.2	82.3	21.	5.9	18.1
Lupine, yellow (3)	6	160.	50.8	29.6	6.7	8.8
Maize, stalks	4	150.	45.3	4.8	3.8	16.4
" "	6	200.	47.9	8.9	3.5	15.4
" fodder, with ears	1	78.5	49.1	17.6	5.4	8.9
" " without ears	1	91.2	37.4	10.4	2.9	14.
Meadow hay	4	143.	59.8	15.6	4.3	16.
" " (393)	6	137.	64.6	14.7	4.1	13.2
" " best (141)	6	146.	71.4	19.2	4.8	15.2
" " poor (145)	6	138.	53.6	10.9	3.4	11.
Meadow hay, in localities with weak-boned animals	4	140.	44.5	14.4	2.3	12.
Meadow fescue (*Festuca pratensis*)	1	88.9	80.8	9.9	4.	21.
Meadow foxtail (*Alopecurus pratensis*)	1	153.5	52.4	15.4	4.4	19.9
Millet, common	1	97.5		12.8	4.9	16.9
" Japanese	8	104.5	58.	11.1	4.	12.2
" different species (2)	6	150.	73.6	7.3	2.9	4.8
" " "	5	150	74.	7.4		

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Millet (*Panicum miliaceum*)....	1	97.5		12.8	4.9	16.9
" Japanese..................	1	104.5	58.	11.1	4.	12.2
Mustard, white, beginning to full bloom (7)....................	6	150.	74.5	17.7	8.1	13.6
Oats, in bloom (6)................	6	115.	61.1	11.9	6.7	25.4
Orchard grass (*Dactylis glomerata*) (10)...................	1	99.	60.	13.		
Orchard grass (*Dactylis glomerata*).........................	1	88.4	64.2	13.1	4.1	18.8
Orchard grass (*Dactylis glomerata*).........................	4	143.	50.8		3.6	16.7
Orchard grass (*Dactylis glomerata*), cut in bloom (11)......	6	143.	64.3	13.1	3.7	16.9
Ox-eye daisy (*Chrysanthemum Leucanthemum*).............	1	96.5	63.7	2.8	4.4	12.5
Pea (*Lathyrus sylvestris*) in bloom (10)..................	6	172.	60.8	33.1	5.1	16.9
Pea, green.......................	4	167.	62.4	22.9	6.8	23.2
" cow, whole plant (8)*.......	1	107.	75.	26.6		
" " " "	1	109.5	84.	19.5	5.2	14.7
" " (8)..........	1	107.	75.	26.6		
" (*Lathyrus sylvestris*) (3)...	6	150.	51.1	19.4	2.7	6.3
" " "	5	140.	48.	19.2		
Perennial rye grass (*Lolium perenne*)....................	1	91.3	67.9	12.3	5.6	15.5
Perennial rye grass (*Lolium perenne*)....................	4	143.	58.2	16.3	6.2	20.2
Perennial rye grass (*Lolium perenne*), cut in bloom (11)..	6	132.5	100.2	17.7	7.4	24.1
Perennial rye grass (*Lolium perenne*) cut in bloom........	5	143.	65.	16.3		
Poa maritima....................	4	150.	57.9		2.6	6.6
Red-top (*Agrostis vulgaris*) (9)..	1	89.	52.	12.6		
" " "	1	77.1	45.9	11.5	3.6	10.2
Red-top (*Agrostis vulgaris*) cut in bloom (3)................	1	87.	49.	12.8		
Rowen of mixed grasses	1	185.2	95.7	16.1	4.3	14.9
Sainfoin (*Onobrychis sativa*), in bloom	1	121.7	75.5	26.3	7.6	20.2
Sainfoin (*Onobrychis sativa*), in bloom	4	167.	45.8	22.1	4.6	13.

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Sainfoin *(Onobrychis sativa)*, in bloom	2	149.	58.	21.3		
Sainfoin *(Onobrychis sativa)*, in bloom (29)	6	155.	52.4	21.2	4.6	13.2
Sainfoin *(Onobrychis sativa)*, beginning of bloom (6)	6	157.5	67.	24.6	5.	14.7
Sainfoin *(Onobrychis sativa)*, beginning of bloom	5	158.	67.	24.6		
Sainfoin *(Onobrychis sativa)*, in bloom	5	167.	62.	21.3		
Salt marsh hay	8	53.6		11.8	2.5	7.2
Serradella *(Ornithopus sativus)*	1	73.9	106.	27.	7.8	6.5
" " "	4	167.	81.6	21.6	9.1	31.9
" " "	2	150.	72.	24.3		
Serradella *(Ornithopus sativus)* beginning to end of bloom (9)	6	160.	67.3	24.7	7.4	26.3
Serradella *(Ornithopus sativus)* in bloom	5	160.	81.	25.9		
Serradella *(Ornithopus sativus)*	1	73.9	106.	27.	7.8	6.5
" " " (1)	6	150.	54.9	20.7	4.2	12.7
Setaria Germanica (23)	6	124.	58.5	13.9	3.6	22.2
Scotch tares	1	158.		29.6	8.2	30.
Spurry *(Spergula arvensis)* (9)	6	150.	91.	16.4	8.7	21.2
Sedge, creek *(Spartina stricta*, var. *glabra)* (5)	1	83.	107.	10.6		
Tall meadow oat-grass *(Arrhenatherum avenaceum)*	1	153.5	49.2	11.6	3.2	17.2
Teosinte *(Euchlæna luxurians)*	1	60.6	65.3	14.6	5.5	37.
Timothy *(Phleum pratense)* (68)	1	132.	44.	9.4		
" " "	1	75.2	49.3	12.6	5.3	9.
" " " (69)	6	143.	41.1	10.	5.	14.1
Timothy *(Phleum pratense)*, cut in full bloom (12)	1	150.	45.	8.4		
Timothy *(Phleum pratense)*, cut soon after bloom (11)	1	142.	44.	9.1		
Timothy *(Phleum pratense)* cut when nearly ripe (12)	1	141.	39.	8.		
Vetch, kidney *(Anthyllis vulneraria)* in bloom	4	167.	53.2	22.1	4.7	14.5

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Vetch, kidney (*Anthyllis vulneraria*) in bloom	2	151.	60.	15.5		
Vetch, kidney (*Anthyllis vulneraria*) in bloom (12)	6	160.	55.9	15.	4.5	12.
Vetch (*Vicia Cracca*), beginning to end of bloom (5)	6	165.	43.2	27.7	4.6	14.6
Vetch (*Vicia Cracca*), beginning of bloom	5	156.	58.	37.		
Vetch (*Vicia Cracca*), in bloom	5	165.	43.	29.7		
Vetch (*Vicia dumetorium*), in bloom (1)	6	160.	52.	33.8	5.5	17.6
Vetch (*Vicia sepium*), in bloom (1)	6	167.	61.	30.7	6.4	20.4
Vetch (*Vicia sativa*), in bloom (7)	6	167.	87.*	27.9	7.3	23.3
Vetch (*Vicia villosa*), in bloom (2)	6	160.	84.1	36.8	9.7	24.4

X. Leaves, etc., of Vegetables—

		Lbs. in 1,000.				
Artichoke, Jerusalem (*Helianthus tuberosus*)	4	800.	14.5	5.3	.7	3.1
Artichoke, Jerusalem (*Helianthus tuberosus*) (4)	6	553.2	71.5	5.5	2.8	11.7
Beet, common	4	905.	14.6	3.	1.	4.5
" " (19)	6	890.	19.9	3.8	.9	5.1
" sugar	4	897.	15.3	3.	.7	4.
" " (8)	6	880.	23.9	4.1	1.5	6.2
Cabbage (*Brassica Napus rapifera*)	4	884.	19.6	3.4	2.	2.8
Cabbage (*Brassica Napus rapifera*) (1)	6	870.	16.9	4.3	1.6	2.2
Cabbage (*Brassica oleracea procera*) (7)	6	856.3	14.1	4.2	2.2	5.2
Cabbage	4	890.	15.6	2.4	1.4	5.8
" stems	8	820.	11.6	1.8	2.4	5.1
Carrot	4	822.	23.9	5.1	1.	2.9
" at root harvest (4)	6	818.	42.6	5.5	1.1	2.7
Chicory	4	850.	16.5	3.5	1.	4.3
Corn, cobs	1	801.	5.9	2.1	.5	2.2

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Corn, husks	1	861.9	5.6	1.8	.7	2.2
" stalks	1	808.6	12.5	2.8	1.4	4.1
Mangel-wurzel	8	905.	14.1	3.	.8	4.1
Parsnip, in May (1)	6	831.5	25.9	2.9	.8	2.5
Potato, shortly before harvest	4	770.	19.7	4.9	1.6	4.3
" " " " (3)	6	770.	31.3	4.	1.8	4.6
" July and August	4	825.	16.5	6.3	1.2	4.4
" " " " (6)	6	850.	15.5	5.7	1.2	3.8
Sweet potato	1	800.6	24.5	4.2	.7	7.3
Rhubarb, roots	1	743.5	22.8	5.5	.6	5.3
Succory	8	850.	16.5	3.5	1.	4.3
Tomato vines	1	733.1	117.2	2.4	.6	2.9
" "	1	836.1	30.	3.2	.7	5.
Turnip	4	898.	11.9	3.	.9	2.8
XI. Mill Products—				Lbs. in 1,000.		
Apple pomace	1	805.	2.7	2.3	.2	1.3
" " (5)	6	740.	8.2	2.6	.1	.3
" " dried (1)	6	100.	28.1	8.8	3.6	.9
Barley, flour	4	140.	20.	16.	9.5	5.8
" bran	4	120.	49.5	17.6	9.1	8.3
" " (21)	6	123.	70.	16.5	10.5	9.2
" middlings	4	130.	21.1		10.8	5.5
" " (16)	6	132.	28.5	20.2	17.4	6.9
" ground	1	134.3	20.6	15.5	6.6	3.4
Beer	8	900.	6.2		2.	2.1
Beech-nut cake, unshelled nuts (24)	6	151.	47.2	29.9	10.	6.8
Beech-nut cake, shelled nuts (5)	6	104.5	70.5	58.2	14.3	10.
Brewers' grains, dry	1	91.4	39.2	36.2	10.3	.9
" " " (166)	6	95.	47.2	33.	16.1	2.
" " wet	1	750.1		8.9	3.1	.5
" " "	4	766.	10.6	7.8	3.9	.4
" " " (158)	6	762.2	12.4	8.1	4.2	.5
Buckwheat bran, coarse (5)	6	156.	28.	12.8	4.2	12.7
" " fine (9)	6	120.	70.	24.3	13.2	15.8
" " "	4	140.	29.8	27.2	10.7	9.7
" middlings, coarse (6)	6	120.	47.	50.8	12.3	11.4
" " fine (9)	6	147.	14.	13.8	6.8	3.4

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Buckwheat, hulls	1	119.		4.9	.7	5.2
" " (2)	6	132.	22.3	7.3	4.3	14.7
" "	5	132.	22.	7.4		
Brassica rapa oleifera (35)	6	107.2	77.3	52.3	20.	13.
Cacao cake (5)	6	100.	81.3	30.	32.	26.
" " (20)	6	90.	88.5	72.1	43.3	19.
" "	4	77.	78.5	84.5	40.1	17.5
Cocoa cake or meal	4	127.	53.3	37.4	13.	19.6
" " " " (73)	6	103.5	60.2	32.8	16.	24.
Corn, cobs	1	120.9	8.2	5.	.6	6.
" meal	1	129.5	14.1	15.8	6.3	4.
" "	4	140.	5.9	16.	2.7	1.7
" and cob meal	1	89.6		14.1	5.7	4.7
" middlings, coarse (15)	6	130.	19.4	13.6	4.4	2.6
" " fine (21)	6	152.	14.	15.1	3.	1.7
" sprouts cake (232)	6	114.3	19.2	26.5	8.	5.
Cotton-seed cake, from unshelled seed (46)	6	118.6	63.8	38.8	25.8	16.1
Cotton-seed cake, from shelled seed (84)	6	86.5	70.4	70.6	32.5	15.8
Cotton-seed cake	4	112.	66.4	62.1	30.5	15.8
" hulls (4)	1	104.	26.	6.4		
" "	1	106.3	26.1	7.5	1.8	10.8
" "	6	133.	27.	6.2	4.3	10.4
" meal	1	99.	68.2	66.4	26.8	17.9
" " (142)	6	88.2	70.5	69.	30.4	15.8
Grape pomace, fresh (2)	6	750.	4.1	9.	.5	2.
" " fermented (4)	6	675.	15.6	7.2	2.	7.8
Gluten meal	1	85.9	7.3	50.3	3.3	.5
Hemp-seed cake (33)	6	120.	79.7	49.	25.2	14.
Hominy feed	1	89.3	22.1	16.3	9.8	4.9
Hops, after brewing (5)	6	109.4	64.	24.5	10.8	4.6
" spent	7	755.		10.8	3.2	4.
Lentil, middlings (1)	6	134.	24.	41.3	6.5	7.8
Linseed cake	4	122.	51.3	47.2	16.2	12.5
" " (900)	6	110.	65.5	45.8	16.2	12.5
" meal, o. p.	2	88.8	60.8	54.3	16.6	13.7
" " "	6	90.	60.3	52.1	16.2	12.5
" " n. p.	1	77.7	53.7	57.8	18.3	13.9
" " " (20)	6	110.	62.1	56.4	17.4	13.4

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash	Nitrogen	Phosphoric acid.	Potash.
Malt, green, barley (4)	6	453.5	21.	10.7	2.6	5.5
" " "	4	475.	14.6	10.4	5.3	2.5
" dry, barley	4	75.	25.6	16.	9.3	4.4
" " " (5)	6	120.	28.5	16.2	4.2	8.8
" sprouts, barley	1	183.8	124.8	35.5	14.3	16.3
" " "	4	80.	67.6	36.8	18.2	20.8
" " " (128)	6	120.	75.4	37.	17.4	19.9
" " wheat (3)	6	145.	64.	46.	16.2	18.8
" " corn (3)	6	150.	63.	46.6	16.2	18.7
Mash, wheat, fresh (2)	6	890.5	4.2	3.5	1.9	1.3
" " dry (1)	6	120.	87.	45.9	40.9	27.
" rye, fresh (20)	6	922.	4.1	2.7	1.8	1.2
" " dry (23)	6	106.	73.	37.	33.5	22.4
" corn, fresh (8)	6	913.2	4.6	3.2	19.5	12.2
" " dry (5)	6	94.	44.2	37.1	20.4	12.7
" potato, fresh	4	930.	6.6	1.6	1.3	3.
" " " (33)	6	943.	6.7	1.8	1.1	2.4
" " dry (3)	6	126.3	147.8	33.2	19.7	48.1
Middlings, mixed, best quality (22)	6	128.	33.	22.6	12.2	9.6
Middlings, mixed, poorer quality (22)	6	125.	56.	22.6	26.3	15.3
Millet, bran (5)	6	106.	115.	7.	15.2	12.5
" middlings (3)	6	111.	49.	18.6	21.1	8.9
Molasses slump	8	920.	14.	3.2	.1	11.
Oats, ground	1	111.7	33.7	18.6	7.7	5.9
" bran (4)	6	110.	82.8	13.4	2.2	7.1
" middlings, coarse (6)	6	100.	62.	18.7	22.5	15.3
" " fine (6)	6	100.	52.	26.1	27.	15.3
Oat hulls	8	140.	34.7		1.6	4.9
Olive cake	4	138.	27.8	9.6	2.5	7.9
Palm-nut cake	4	100.	26.1	25.9	11.	5.
" " (600)	6	104.2	42.5	26.9	11.	5.
Pea bran	8	140.	22.7		3.1	10.3
" meal	1	88.5	26.8	30.8	8.2	9.9
" hulls (59)	6	125.	37.	22.4	8.8	10.
" middlings (7)	6	135.	31.	37.4	6.5	7.8
Peanut cake, whole nut (24)	6	111.5	62.2	49.1	15.	18.
" " shelled nut (2480)	6	106.6	48.7	76.2	20.	15.
" " " "	4	104.	39.7	75.6	13.1	15.

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Poppy seed cake (190)	6	114.2	112.1	58.2	31.7	23.
" " "	4	115.	77.4	51.	31.7	23.
Potato slump	8	948.	5.	1.6	1.	2.2
Rape cake	4	113.	57.	50.5	20.	13.
" " (500)	6	100.	79.4	49.6	20.	13.
Rice bran	1	102.	129.4	7.1	2.9	2.4
" " (7)	6	102.	129.4	7.1	2.9	2.4
" middlings	4	100.	54.7	19.1	23.8	6.1
" polish	1	103.	90.	19.7	26.7	7.1
" " (187)	6	106.	92.	17.8	27.7	7.6
Rye flour	1	142.		16.8	8.5	6.5
" "	4	142.	16.9	16.8	8.2	6.5
" bran	1	125.	46.	23.2	22.8	14.
" "	4	125.	71.9	23.2	34.4	19.4
" " (230)	6	125.	46.	23.2	22.8	14.
" middlings	1	125.4	35.2	18.4	12.6	8.1
" " (20)	6	125.	30.	23.2	12.3	9.6
Sesame cake (150)	6	98.2	107.5	60.	32.7	14.5
" "	4	111.	93.8	58.6	32.7	14.5
Soja bean cake (5)	6	125.9	53.5	66.2	22.	18.
Sugar beet, clarifying refuse	8	948.	3.3	.8	.2	.3
" " molasses (35)	6	207.5	106.2	14.6	.5	56.3
" " "	4	172.	82.6	12.8	.5	58.7
Sugar beet diffusion cuttings, after use, fresh (20)	6	930.	8.3	1.	.3	.64
Sugar beet diffusion cuttings, after use, pressed (16)	6	897.7	5.8	1.4	.2	.4
Sugar beet diffusion cuttings, after use, soured (35)	6	885.2	10.9	1.8	.4	.6
Sugar beet diffusion cuttings, after use, dried (12)	6	105.3	66.1	12.5	2.2	3.1
Sunflower seed cake (58)	6	92.4	66.8	55.5	21.5	11.7
" " "	4	103.	49.7	59.7	21.5	11.7
Starch feed, glucose refuse	1	81.		26.2	2.9	1.5
Walnut cake (4)	6	113.7	50.7	49.1	20.2	15.3
" "	4	137.	46.2	55.3	20.2	15.3
Wheat flour	1	98.3	12.2	22.1	5.7	5.4
" "	4	120.	11.2	21.6	5.6	3.5
" bran	1	117.4	62.5	26.7	28.9	16.1
" " coarse (93)	6	132.	58.	22.6	26.9	15.2

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Wheat bran, fine (40)	6	132.	46.	24.8	26.	13.9
" middlings	1	91.8	23.	26.3	9.5	6.3
" " (24)	6	126.	27.	22.8	13.5	7.4

XII. Roots and Tubers—

		Lbs. in 1,000.				
Artichoke, Jerusalem	4	800.	9.8	3.2	1.4	4.7
" " (33)	6	800.	11.2	2.6	1.4	4.7
Canaigre	8	667.	13.7	6.2	1.8	5.6
Beet, common	4	880.	9.1	1.8	.8	4.8
" " (318)	6	880.	10.7	2.	.8	4.8
" red	1	877.3	11.3	2.4	.9	4.4
" yellow fodder	1	906.	9.5	1.9	.9	4.6
Carrot	1	897.9	9.2	1.5	.9	5.1
"	4	850.	8.2	2.2	1.1	3.
" (63)	6	870.	10.	2.	.9	2.6
Chicory	4	800.	6.7	2.5	.8	2.6
Kohlrübe (*Brassica napus esarlenta*)	4	870.	7.5	2.1	1.1	3.5
Kohlrübe *Brassica napus esarlenta*) (110)	6	878.	9.2	2.4	1.	3.3
Mangel-wurzel	1	872.9	12.2	1.9	.9	3.8
Parsnip (3)	6	832.	10.	1.8	2.	4.4
"	1	803.4	10.3	2.2	1.9	6.2
"	4	793.	10.	5.4	1.9	5.4
Potato	1	797.5	9.9	2.1	.7	2.9
"	4	750.	9.5	3.4	1.6	5.8
" with 25% dry matter (197).	6	750.	11.	3.4	1.6	5.7
" " 21% " " (53)..	6	790.	9.3	3.1	1.3	4.8
" " 26% " " (107).	6	740.	11.2	3.3	1.7	5.9
" " 32% " " (13)..	6	680.	11.	4.	2.	7.3
Ruta-bagas	1	891.3	10.6	1.9	1.2	4.9
Succory	8	800.	6.7	2.5	.8	2.6
Sugar beet	1	869.5	10.4	2.2	1.	4.8
" "	4	815.	7.1	1.6	.9	3.8
" " (68)	6	820.	8.1	2.1	.8	3.7
" " upper part of root.....	4	840.	9.6	2.	1.2	2.8
Turnips	1	894.9	10.1	1.8	1.	3.9
"	4	920.	6.4	1.8	.8	2.9
" (52)	6	907.8	8.	1.9	.9	3.4

XIII. Seeds and Seed-like Fruits—

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
		Lbs. in 1,000.				
Acorns, unshelled, fresh (12)	6	500.	11.7	5.4	1.6	7.
" " "	4	553.	9.8	4.	1.5	6.3
Acorns, unshelled, partially dried (12)	6	350.	15.3	6.9	2.1	9.1
Acorns, unshelled, dried (12)	6	150.	20.	9.	2.7	11.9
" shelled, fresh (8)	6	350.	19.5	7.9	2.6	9.3
" " dried (8)	6	150.	25.5	10.4	3.4	12.8
Barley (10)	1	109.	21.	19.8		
"	1	149.		17.6	8.2	5.4
"	2	138.	22.	17.9		
" (1128)	6	143.	24.8	15.1	7.9	4.8
" spring	4	143.	22.3	16.	7.8	4.7
" winter	4	145.	17.	16.	5.6	2.8
Bean, field	4	145.	31.	40.8	12.1	12.9
" "	2	141.	31.	40.2		
" " (87)	6	143.	31.8	40.7	12.	12.9
" garden	4	150.	27.4	39.	9.7	12.1
" " (26)	6	140.	36.	36.4	9.8	12.2
" soja (8)	1	108.	47.	54.4		
" "	1	183.3	49.9	53.	18.7	19.9
" "	4	100.	28.3	53.4	10.4	12.6
" " yellow (23)	6	100.	51.3	52.9	10.4	12.6
" " brown (11)	6	100.	48.5	52.2	10.4	12.6
" " black (5)	6	112.	47.3	54.4	10.2	12.4
" " mixed (58)	6	100.	48.	55.1	10.4	12.6
Beech, European (*Fagus sylvatica*)	4	150.	27.	23.5	6.3	8.3
Beech, European (*Fagus sylvatica*) (3)	6	111.	41.8	21.3	4.7	5.2
Beet, mangel (*Beta vulgaris*)	4	140.	48.8		7.6	9.1
" " " " (6)	6	139.	69.4	19.1	7.6	9.
Buckwheat (8)	1	126.	20.	16.		
"	1	141.		14.4	4.4	2.1
"	4	140.	11.8	14.4	5.7	2.7
"	2	131.	18.	16.2		
" (20)	6	141.	27.7	18.1	6.9	3.
Caraway (*Carum Carui*)	4	130.	46.4		11.3	12.2
Carrot (*Daucus Carota*)	4	120.	74.8		11.8	14.3

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen	Phosphoric acid.	Potash.
Castor pomace		7.04		6.	1.05	.34
Chestnut, horse, common (*Æsculus Hippocastanum*) dried and shelled (10)	6	105.	23.3	11.5	4.7	12.5
Chestnut, horse (*Æsculus Hippocastanum*) fresh	4	193.	12.	6.9	2.7	7.1
Chicory (*Cichorium Intybus*)	4	130.	54.6		16.5	6.5
Clover, red	4	150.	38.3	30.5	14.5	13.5
" white	4	150.	33.8		11.6	12.3
Cocoa-nut	4	466.	9.7	8.8	1.7	4.3
Coriander (*Coriandrum sativum*)	4	135.	41.2		7.6	14.5
Cotton	8	77.	33.8	36.5	10.5	10.9
Fennel (*Fœniculum officinale*)	4	134.	61.4		10.1	19.6
Flax, false (*Camelina sativa*) (5)	6	77.	71.4	38.3	20.3	3.5
Grape	8	110.	22.7	19.	7.	6.9
Hemp (*Cannabis sativa*)	4	122.	46.3	26.1	16.9	9.4
" " "	2	122.	45.	26.1		
" " " (5)	6	89.	42.4	29.2	17.5	9.7
Lentil, common, of Europe (*Lens esculenta*)	2	125.	28.	38.1		
Lentil, common, of Europe (*Lens esculenta*) (14)	6	140.	29.8	40.7	7.7	8.6
Linseed (*Linum usitatissimum*)	4	118.	32.6	32.8	13.5	10.
" " "	2	118.	34.	34.7		
" " " (50)	6	92.	43.	36.1	13.9	10.3
Lupine (*Lupinus luteus*) yellow	2	128.	35.	56.6		
" " " " (41)	6	140.	38.1	61.2	14.1	11.3
" (*L. angustifolius*) blue	2	150.	32.	44.8		
" " " (13)	6	140.	29.	47.2	13.8	11.2
" (*L. albus*) white (10)	6	140.	30.4	47.3	13.8	11.2
" (*L. hirsutus*) (5)	6	140.	27.3	40.8	12.9	10.3
"	4	130.	37.	56.6	14.2	11.4
" minus alkaloid	6	325.	11.	50.7	5.1	4.1
Madia sativa (4)	6	75.	42.7	31.	17.6	9.3
" "	5	84.	47.	33.		
Maize (Indian corn), dent (86)	1	106.	15.	16.4		
" " " " (149)	6	130.	14.8	16.	5.7	3.7
" " " flint (68)	1	113.	14.	16.8		
" " " " (80)	6	130.	14.	16.4	5.7	3.7
" " " sweet (26)	1	88.	19.	18.6		
" " " " (27)	6	130.	18.2	18.4	5.7	3.7

Sample (No. of analyses in parentheses).	Authority	Water	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Maize (Indian corn), pop (4)	1	107.	15.	17.9		
Maize (Indian corn), dent, field cured (17)	1	342.	9.	10.		
Maize (Indian corn), flint, field cured (48)	1	271.	13.	12.8		
Maize (208)	1	109.	15.	16.8		
"	1	108.8	15.3	18.2	7.	4.
"	4	144.	12.4	16.	5.7	3.7
"	5	127.	17.	17.		
" (300)	6	130.	13.	15.8	5.7	3.7
Millet, common (*Panicum miliaceum*)	1	126.8		20.4	8.5	3.6
Millet, common (*Panicum miliaceum*)	4	140.	29.5	20.3	6.5	3.3
Millet, common (*Panicum miliaceum*)	2	135.	30.	20.3		
Millet, common (*Panicum miliaceum*) (6)	6	125.	38.2	17.	5.9	3.4
Millet, Japanese (*Setaria Italica* vars.)	1	136.8		17.3	6.9	3.8
Millet (*Setaria Italica*)	2	124.	33.	16.		
Mustard	4	130.	36.5		14.6	5.9
Mustard, black (*Brassica nigra*) (11)	6	63.	50.2	44.1	15.7	6.4
Mustard, white (*B. alba*) (6)	6	72.	43.6	43.5	15.6	6.3
Oats (30)	1	110.	30.	18.8		
"	1	181.7	29.8	20.6	8.2	6.2
"	4	143.	26.7	17.6	6.8	4.8
"	2	137.	27.	19.2		
" (560)	6	133.	31.	16.5	6.9	4.8
" hulled (180)	6	120.	20.3	21.6	8.8	5.1
Pea (*Lathyrus sativus*) (4)	6	140.	27.8	38.	4.7	9.7
" " "	2	116.	29.	40.		
Peas	4	143.	23.4	35.8	8.4	10.1
"	2	132.	24.	35.8		
" (118)	6	140.	28.1	36.	8.4	10.1
" cow (5)	1	148.	32.	33.3		
Poppy, opium (*Papaver somniferum*)	4	147.	51.5	28.	16.2	7.

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Poppy, opium (*Papaver somniferum*) (9)	6	81.	72.3	31.2	17.5	7.5
Peanut (*Arachis hypogæa*) (9)	6	70.	28.3	47.5	10.	8.
" " "	4	63.	32.	45.1	12.4	12.7
Rape (*Brassica Napus oleifera DC.*)	4	118.	39.2	31.2	16.6	9.6
Rape (*Brassica Napus oleifera DC.*) (22)	6	73.	42.1	31.7	17.4	10.1
Rape (*Brassica Rapa oleifera DC.*) (13)	6	78.	38.1	32.8	15.7	9.2
Rape (*Brassica Rapa oleifera DC.*) short season var.	4	120.	34.9	36.8	14.9	7.7
Rape (*Raphanus sativus oleiferus*) (2)	6	77.	35.7	34.	14.6	9.2
Rice (10)	1	124.	4.	11.8		
"	1	126.	8.2	10.8	1.8	.9
"	2	132.	7.	13.8		
" (41)	6	126.	8.2	10.8	1.8	.9
" not hulled	2	85.	4.	8.		
Rutabaga	8	140.	48.8		7.6	9.1
Rye (6)	1	116.	19.	16.9		
"	1	149.		17.6	8.2	5.4
"	2	143.	18.	18.2		
" (257)	6	134.	19.8	18.3	8.6	5.8
" spring	4	143.	18.		9.2	6.2
" winter	4	143.	17.9	17.6	8.5	5.8
Sainfoin, esparsette (*Onobrychis sativa*)	4	160.	38.4		9.2	11.
Serradella (*Ornithopus sativus*)	4	120.	28.4	34.9	7.8	8.2
" " "	2	87.	34.	35.2		
" " " (7)	6	140.	31.	34.3	7.7	8.
Sesame (*Sesamum orientale*) (12)	6	55.	64.7	32.5	17.	8.
Sorghum (10)	1	128.	21.	14.6		
"	1	140.		14.8	8.1	4.2
"	4	140.	16.		8.1	3.3
" saccharatum (38)	6	152.	17.1	14.8	8.1	3.2
" Tataricum (6)	6	111.	24.2	15.3	6.	3.6
" vulgare (12)	6	114.6	19.5	14.3	8.4	3.4
" saccharatum Pers.	4	140.	23.4		5.8	3.5
Spelt	2	121.	30.	17.6		

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Spelt, with husk	4	148.	36.6	16.6	7.6	5.7
" " " (11)	6	137.	23.4	17.4	7.6	5.7
" without husk	4	143.	14.4	22.	6.5	4.3
" " " (6)	6	139.	18.4	22.2	6.5	4.3
Spurry (*Spergula arvensis*)	2	103.	34.	22.4		
" " " (3)	6	103.	34.	22.4	7.2	3.6
Sunflower (*Helianthus annuus*) (5)	6	75.	34.4	22.8	12.2	5.6
Turnips	8	125.	34.9	34.	14.	7.6
Vetch, kidney (*Anthyllis vulneraria*)	4	94.	36.8		13.6	12.1
Vetch, or tare (*Vicia sativa*)	4	143.	26.6	44.	9.9	8.
" " " " "	2	136.	27.	44.		
" " " " " (13)	6	133.	32.3	40.6	9.9	8.1
Vetch, Russian, or hairy (*Vicia villosa*) (4)	6	160.	30.2	37.	9.6	8.4
Walnut, kernel	4	450.	11.7		5.1	3.6
Wheat (1358)	6	134.	17.1	19.3	8.7	5.5
"	2	143.	17.	21.1		
" hard-glassy (239)	6	134.	17.9	20.2	8.7	5.5
" soft (146)	6	134.	17.8	18.2	8.7	5.5
" spring (13)	1	104.	19.	20.		
" "	1	143.5	15.7	23.6	7.	3.9
" "	4	143.	18.3	20.5	9.	5.6
" " (132)	6	134.	19.4	21.2	9.1	5.6
" winter (262)	1	105.	18.	18.8		
" "	1	147.5		23.6	8.9	6.1
" "	4	144.	16.8	20.8	7.9	5.2
" " (788)	6	134.	18.2	18.7	8.	5.3

XIV. Straw—

		Lbs. in 1,000.				
Barley	1	114.4	53.	13.1	3.	20.9
"	4	143.	45.9	6.4	1.9	10.7
"	2	143.	44.	5.4		
" (101)	6	142.	57.4	5.5	2.	10.6
" spring	5	143.	41.	5.6		
" winter	5	143.	55.	5.3		
Bean, field	4	160.	44.9	16.3	2.9	19.4
" "	2	175.	58.	15.8		
" " (9)	6	184.	54.3	13.	2.7	18.7

Sample (No. of analyses in parentheses).	Authority	Water	Ash.	Nitrogen.	Phosphoric acid	Potash.
Bean, field	5	160.	46.	16.3		
" garden	4	160.	40.2		3.9	12.8
" " (6)	6	150.	75.	13.9	3.9	13.
" "	5	150.	62.	11.2		
" soja	1	130.		17.5	4.	13.2
" "	4	140.	32.7	13.1	3.1	5.
" "	2	112.	12.4	12.5		
" " (10)	6	160.	101.8	11.8	2.9	4.8
" "	5	150.	102.	10.7		
Clover, grown for seed	2	155.	58.	14.7		
" " " "	5	160.	56.	15.		
" red	6	155.	58.	14.7	4.2	12.6
Lentil, common, of Europe (*Lens esculenta*)	2	150.	66.	22.4		
Lentil, common, of Europe (*Lens esculenta*) (2)	6	150.	68.4	22.2	2.7	6.3
Lentil, common, of Europe (*Lens esculenta*)	5	160.	65.	22.4		
Lupine (*Lupinus luteus*)	4	160.	42.6	9.4	2.5	17.7
" " "	2	126.	38.	8.8		
" " " (14)	6	150.	39.5	10.6	2.5	17.9
" " "	5	160.	41.	9.4		
Oats (12)	1	92.	51.	6.4		
"	1	90.9	47.6	6.2	2.	12.4
"	4	143.	61.6	5.6	2.8	16.3
"	2	143.	41.	6.4		
" (55)	6	145.	57.	4.6	2.8	17.7
"	5	143.	40.	6.4		
Pea	4	160.	43.1	10.4	3.5	9.9
"	2	143.	49.	11.7		
" (53)	6	136.	66.	14.3	3.5	10.2
"	5	160.	45.	10.4		
Poppy, opium (*Papaver somniferum*)	4	160.	48.6		1.6	18.4
Poppy, opium (*Papaver somniferum*) (2)	6	160.	87.3	9.7	1.6	18.4
Poppy, opium (*Papaver somniferum*)	5	148.	94.	10.7		
Rape (*Brassica Napus oleifera*)	4	160.	41.3	5.6	2.5	11.3
" " " "	2	160.	53.	5.6		

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Rape (*Brassica Napus oleifera*) (2)	6	160.	37.8	4.	2.5	11.2
" " " " ..	5	160.	41.	5.6		
Rice (7)	6	132.	103.3	8.8	2.6	5.3
"	5	156.	153.	9.1		
Rye (7)	1	71.	32.	4.8		
"	1	76.1	32.5	4.6	2.8	7.9
"	2	143.	41.	4.8		
" (87)	6	136.	41.5	4.9	2.5	8.6
" spring	4	143.	46.7	5.6	2.8	11.7
" winter	4	143.	38.2	4.	2.5	8.6
" "	7	143.	41.	4.8		
Spelt	2	143.	52.	3.7		
" (2)	6	150.	58.1	4.3	2.5	5.2
" winter	4	143.	50.1	4.	2.6	5.2
" "	5	143.	50.	4.		
Vetch, Russian or hairy (*Vicia villosa*) (3)	6	150.	41.8	10.9	2.7	6.3
Vetch, Russian or hairy (*Vicia villosa*)	5	113.	48.	9.9		
Vetch (*Vicia sativa*)	4	160.	44.1	12.	2.7	6.3
" " "	2	143.	60.	11.2		
" " " (7)	6	133.	52.9	14.4	2.7	6.5
" " "	5	160.	45.	12.		
Wheat, winter	4	143.	46.	4.8	2.2	6.3
" "	5	143.	46.	4.8		
" spring	4	143.	38.1	5.6	2.	11.
" " (7)	1	96.	42.	5.4		
" "	1	125.6	38.1	5.9	1.2	5.1
" "	2	143.	30.	5.		
" " (80)	6	136.	53.	6.	2.2	6.3

XV. Vegetables—

		Lbs. in 1,000.				
Artichoke	4	811.		10.1	3.9	2.4
Asparagus	1	939.6	6.7	2.9	.8	2.9
"	4	933.	5.	3.2	.9	1.2
Beans, Adzuki	1	158.6	35.3	32.9	9.5	15.1
" Lima	1	684.6	16.9			
" string	1	872.3	7.6			
Beets, red	1	884.7	10.4	2.4	.9	4.4

Sample (No. of analyses in parentheses).	Authority.	Water.	Ash.	Nitrogen.	Phosphoric acid.	Potash.
Cabbage	1	905.2	14.	3.8	1.1	4.3
Carrots.	1	885.9	10.2	1.6	.9	5.1
Cauliflower	1	908.2	8.1	1.3	1.6	3.6
"	4	904.	8.	4.	1.6	3.6
Celery	4	841.	17.6	2.4	2.2	7.6
Chives	4	820.	9.9	6.2	1.5	3.3
Chorogi tuber	1	789.	10.9	4.1	1.9	6.4
Corn, sweet, kernels	1	821.4	5.6	4.6	.7	2.4
Cucumber	1	959.9	4.6	1.6	1.2	2.4
"	4	956.	5.8	1.6	1.2	2.4
Garlic, tuber.	4	876.	8.4	4.5	1.4	2.6
" leaves	4	908.	7.6	3.4	.6	3.1
Horse-radish	1	766.8	18.7	3.6	.7	11.6
" "	4	767.	19.7	4.3	2.	7.7
Lettuce, Roman	4	925.	9.8	2.	1.1	2.5
" whole plant	1	936.8	16.1	2.3	.7	3.7
" " "	4	943.	10.3	2.2	1.	3.9
" " "	4	940.	8.1		.7	3.7
Kohl-rabi	1	910.8	12.7	4.8	2.7	4.3
"	4	850.	12.3	4.8	2.7	4.3
Mushroom	4	888.	10.	4.7	3.4	5.1
Onion	1	875.5	5.7	1.4	.4	1.
"	4	860.	7.4	2.7	1.3	2.5
Parsnip	1	803.4	10.3	2.2	1.9	6.2
Peas	1	126.2	31.1	35.8	8.4	10.1
Pumpkin	1	922.7	6.3	1.1	1.6	.9
"	4	900.	4.4	1.1	1.6	.9
Radish	4	933.	4.9	1.9	.5	1.6
Rhubarb, stems and leaves	1	916.7	17.2	1.3	.2	3.6
Spinach	1	924.2	19.4	4.9	1.6	2.7
"	4	903.	16.	4.9	1.6	2.7
Sweet potato	1	729.6	9.5	2.3	1.	5.
" "	4	758.	7.4	2.4	.8	3.7
" "	1	712.6	10.	2.4	.8	3.7
Tomato	1	936.4	4.7	1.6	.5	2.7
Turnip	1	904.6	8.	1.8	1.	3.9

NOTE.—By moving decimal points one place to the left, the reader may make the figures express percentages.

APPENDIX B.

NOTES TO THE SECOND EDITION.

Since Chapter IV. was written, great interest has been shown in the cultivation of the sugar beet. Success in this branch of agriculture is so dependent upon a continuous and full supply of moisture, that the subject of providing and conserving it takes on a new and added interest.

All writers on sugar beet culture recommend deep preparation of the soil for this crop, not alone deep ordinary plowing, but subsoiling; that is, loosening the soil by both operations to the depth of twelve or more inches. The reason usually given for this deep tillage is, that the beet tends to grow out of the ground if the tap-root reaches a hard subsoil before the beet has extended its tap-root full length. All this is true, and it is also a fact that that part of the beet which is exposed to the direct rays of the sun, or, that above ground, has not only a less per cent of sugar than the part underground, but also contains a greater per cent of impurities which arrest the crystallization of what sugar may be present in the exposed crowns; therefore the land designed for beets should be broken up and loosened by the action of the subsoiler, which should immediately follow the ordinary plow. But it may easily happen that the subsoiling may do positive injury to the succeeding crop. While deep preparatory tillage may, and usually does, allow the root to descend easily, subsoiling, if not performed at the proper time, or if it is not followed by suitable surface tillage, often arrests capillary action by leaving the subsurface soil,—or that which has been loosened by the subsoiler,—so porous and non-compacted as to arrest energetic capillary action. The fact is, that deep and thorough preparation of the

land sets free or makes available plant-food, and may also increase the moisture-storing capacity of the soil. In some cases, subsoiling may dimininish the capacity of the subsurface soil to hold moisture or to lift it to the surface soil, as in case of a subsoil already porous enough or too porous.

If, then, the subsoil needs to be loosened for the purpose of liberating plant-food and for giving the root easy passage downward, as it does in most cases, unusual care should be taken to have the subsurface soil so compacted before the roots reach it that it will be fitted in the highest degree both for retaining moisture and for lifting it towards the surface. If the subsoiling is done in the early fall, the winter rains and frosts will fit this subsurface soil for highest efficiency. If the subsoiling is deferred until spring, it will require some judgment to discover just how much tramping of the teams and pressure of the implements will be necessary to suitably compact the soil loosened by the subsoiler.

The sugar beet requires a fairly full and continuous supply of moisture throughout the entire growing season, for if the beet suffers seriously from lack of moisture in the mid-career of its growth, it will tend to ripen, and many of the leaves will fall off. Later, when the September rains occur, it may make a second growth, and beets which contained from 12 to 15 per cent of sugar at the close of August may be so far depleted of their sugar content by this second growth as to contain but 8 to 10 per cent by the first day of October. It will be seen how necessary it is to keep the beets fully and continuously supplied with moisture until the normal season of ripening approaches. It is not enough to simply deepen the soil and increase its moisture-holding capacity: the moisture should, so far as possible, be conserved. The tramping and compacting of the surface soil by the workmen, when weeding and thinning, restores the capillarity of the surface soil, and there is great loss of moisture unless the earth-mulch is speedily restored by surface tillage. Then, too, neglect to preserve the earth-mulch until late in the season may result in premature ripening and a second growth, which is so destructive to the quality of the beet.

What has been said as to losses which may occur in beet culture by neglect to conserve moisture in a dry time, is measurably true when applied to other inter-tilled crops. Manifestly, plants cannot arrive at their maximum development if, for considerable periods of time, they suffer for a full supply of moisture, though the land may have been prepared in the best manner, good seed used, and the soil fully supplied with available plant-food. There is no sufficient vehicle to carry the nutriment into the plant. Therefore, too much care cannot be taken to conserve moisture in our erratic climate.

The following brief extracts give in clear language the science of capillary attraction as applied to soil moisture:*

"After gravity has removed the surplus of free water beyond the zone of plant roots, then what remains is largely within the control of the tiller of the soil. The product of the season on a fertile soil is largely the measure of his use of this water supply and the per cent he can make available to the growing crop. . . . . But why should water in a half-saturated soil rise to the surface and be thus exposed to loss by evaporation? It gravity cannot overcome the adhesive force of the exposed soil-grain surfaces and carry it down, what power lifts it up? If water will not descend from a half-saturated soil into dry soil beneath, what causes it to ascend? When the soil is fully saturated, gravity controls and the movement of water is downward only. Gravity is the important factor in removing the free water in a pervious soil. When the moisture content is reduced to one-fourth saturation, the movement of water practically ceases between these two points, and especially between half and quarter saturation, the movement may be in any direction, surface tension being the motive power. There are two important factors in the movement of soil water after drainage has ceased. One, the thickness of the water films spread over the soil-grains. The other, their continuity. The exposed surfaces in a cubic foot of clay loam soil should, if laid out flat, cover nearly an acre of ground. A fine division

*H. R. Hilton in Prairie Farmer, January 29, 1898.

and uniform arrangement of the soil particles increase the amount of surface, and hence the quantity of water each foot will retain. If a broad rubber band is slipped over a marble and pulled with a gentle pressure, the marble will represent the soil-grain and the rubber band the film of moisture adhering to it. Stretch the rubber band to its fullest limit, its thickness is diminished, its tension increased; as the pull on the rubber band is slackened it becomes thicker, and is finally restored to its normal condition. When the rubber band is thickest it has the least grip on the marble; as it becomes thinner by stretching, its tension or grip on the marble is increased. In a similar way the water adheres to the soil-grains with least force when the film is thickest and the surface exposed to the air is least, and with greatest force when the film is thinnest and the surface exposed to the air is greatest. When the film is thinnest its strain or tension is greatest, and it is this strain or force that moves the water from the point in the soil where the films are thickest to the point in the soil where they are thinnest till the differences are adjusted. This movement has a limitation not yet clearly determined, but the thick films are more elastic than the thin ones, and will move more readily—that is to say—the movement from soil 25 per cent moist into adjoining soil 20 per cent moist will be more free and rapid than when the differences are 20 and 15 per cent. The freedom of movement is probably in proportion to the difference in moisture content down to the point where the film is most attenuated, but still unbroken. When the film breaks, movement ceases. It is like a broken electric current."

Plant-food used by the sugar beet crop.—The following figures relative to the plant-food used by the beet crop are based upon work done at the Cornell Experiment Station, and reported in Bulletin No. 143, pp. 570 572:

	Nitrogen. %	Potash. %	Phosphoric acid. %	Water. %
Trimmed beets	.28	.36	.11	79.6
Sugar beet crowns...........	.43	.45	.12	79.7
Sugar beet leaves............	.64	1.09	.11	77.7

The proportion of crowns and leaves will, of course, vary considerably with variety, soil, tillage and maturity. The results obtained from an examination of quite a large number of whole plants indicate that on an average there are 57 per cent of trimmed beets, 17 per cent of crowns, and 26 per cent of leaves: or to produce one ton of trimmed beets ready for shipment to the factory, there would also be grown 596 pounds of crowns and 912 pounds of leaves.

The plant-food used in the production of one ton of marketable sugar beets is shown in the following table:

	Nitrogen, lbs.	Potash, lbs.	Phosphoric acid, lbs.	Water, lbs.
One ton trimmed beets..........	5.60	7.20	2.20	1,592
591 pounds of crowns..............	2.56	2.68	.72	475
912 pounds of leaves...............	5.84	9.94	1.	708
Total plant-food used in producing one ton of trimmed beets......	14	19.82	3.92	
A crop of 12 tons per acre will use..	168	237.84	47.04	

It is usual, however, to leave the crowns and leaves on the land, where they quickly decay and give up their fertilizing constituents to succeeding crops. The amount of fertility removed from an acre of land by taking away only the twelve tons of trimmed beets would be: Nitrogen 67.2, potash 86.4, and phosphoric acid 26.4 pounds.

The following table gives the fertilizing constituents of one ton of beet pulp, beet molasses and lime-cake:

	Nitrogen, lbs.	Potash, lbs.	Phosphoric acid, lbs.	Water, lbs.
One ton extracted corsittas or beet pulp............................	1.82	1.72	.32	1,828
One ton beet molasses..............	21.40	65.20	.34	832
One ton of lime-cake from the purifying tanks.....................	2.48	3.05	8.47	871

Note to the Discussion of Superphosphates, Pages 298–302.

The term "superphosphates" is somewhat misleading when we come to consider the nature of the substances commonly known as "double phosphates." A better method of naming is mentioned by Wiley*: that the term "acid phosphate" be

*Agricultural Analysis ii. 150.

applied to the product of the action of sulfuric acid on tricalcium phosphate, and "superphosphate" when the acting acid is phosphoric acid. In either case the same compounds of lime and phosphoric acid may be formed, but when phosphoric acid is the active agent there is no gypsum produced. So that the true "superphosphate" may differ from the ordinary "acid phosphate" only in the absence of gypsum. It may, in consequence, carry as high as three times as much available phosphoric acid as the ordinary acid phosphate.

The phosphoric acid which is used in the manufacture of these superphosphates is obtained from tricalcium phosphate by the action of an excess of sulphuric acid. The reaction may be represented by the equation:

$$\left.\begin{matrix} CaO \\ CaO \\ CaO \end{matrix}\right\} P_2O_5 + \begin{matrix} H_2SO_4 \\ H_2SO_4 \\ H_2SO_4 \end{matrix} = \left.\begin{matrix} H_2O \\ H_2O \\ H_2O \end{matrix}\right\} P_2O_5 + \begin{matrix} CaSO_4 \\ CaSO_4 \\ CaSO_4 \end{matrix}$$

Here, all the calcium of the tricalcium phosphate unites with the sulfuric acid to form gypsum, and the phosphoric acid, P_2O_5, is united to three parts of water, H_2O. This compound with water $\left(\left.\begin{matrix} H_2O \\ H_2O \\ H_2O \end{matrix}\right\} P_2O_5\right)$ is the true phosphoric acid of the chemist, while the substance designated by P_2O_5 is the phosphoric acid of the agriculturist. The phosphoric acid made in this way can be separated from the gypsum by distillation and used to act on more tricalcium phosphate.

$$\left.\begin{matrix} CaO \\ CaO \\ CaO \end{matrix}\right\} P_2O_5 + \left.\begin{matrix} H_2O \\ H_2O \\ H_2O \end{matrix}\right\} P_2O_5 = \left.\begin{matrix} CaO \\ H_2O \\ H_2O \end{matrix}\right\} P_2O_5 + \left.\begin{matrix} H_2O \\ CaO \\ CaO \end{matrix}\right\} P_2O_5$$

Some of the calcium of the tricalcium phosphate unites with the free phosphoric acid and becomes replaced by water (H_2O), thus forming both mono- and dicalcium phosphates, which together constitute available phosphoric acid. There is no gypsum produced in this reaction, because there is no sulfuric acid present. When phosphatic fertilizers are to be transported long distances, there is much saving in freight by using high grade products, which may contain as high as 40 per cent of available phosphoric acid.

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